AL-BAHA UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEEING DEPARTMENT

LABORATORY MANUAL

BY
CIVIL ENGINEERING DEPARTMENT

Laboratory Manual
First Edition-2023

Faculty of Engineering

Al-Baha University

Vision of Faculty of Engineering

Excellence in engineering education, scientific research and community service.

Mission of Faculty of Engineering

Preparation of distinguished engineering cadres that are able to keep up with the needs of the labor market and providing innovative research that contribute in solving engineering and environmental problems for the community, in addition to providing a good environment for learning.

Mission of Civil Engineering Department

Providing sophisticated academic education to graduate qualified civil engineers to meet the needs of the labor market, contribute to community service, and keep up with the professional development process through self-learning and scientific research.

Objectives of Civil Engineering Department

The objectives of the civil engineering program are summarized as follows:

- Prepare graduates to become qualified engineers in the field of civil engineering.
- Prepare graduates to work and communicate professionally and ethically with stakeholders in the labor market.
- Prepare qualified graduates to be admitted to postgraduate programs.

MESSAGE FROM THE HEAD OF CIVIL ENGINEERING DEPARTMENT

We are delighted to have you join us as we embark on each new academic year. Our department provides students with the highest quality education in civil engineering, and we are proud of our commitment to excellence. Our faculty and staff are passionate about their work and strive to create an environment that encourages learning, innovation, and collaboration.

As a student in our department, you will have access to a wide range of courses and research opportunities. We offer courses in structural engineering, geotechnical engineering, water resources engineering, transportation engineering, construction management, environmental engineering, and more. Our faculty members are experts in their fields and will provide you with the knowledge and skills necessary for success in your chosen career path.

In addition to our course offerings, we also provide students with numerous research opportunities. Our faculty members are actively engaged in research projects that span a variety of topics related to civil engineering. We encourage students to participate in these projects as they gain valuable experience while making meaningful contributions to the field.

We also offer several student organizations that provide opportunities for networking and professional development. These organizations host events throughout the year such as guest lectures from industry professionals, panel discussions with alumni, field trips to local construction sites, and more.

Finally, our department is committed to providing students with the resources they need for success both inside and outside of the classroom. We look forward to having you join us! If you have any questions or concerns, please do not hesitate to reach out – we're here for you.

Dr. Abdulaziz Alzahrani

Assistant Professor and Head of Civil Engineering Department

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1. Preface

Welcome to the Laboratories Manuals for Civil Engineering at Al-Baha University! This Manual is designed to be a valuable resource for students enrolled in the Civil Engineering program. It provides detailed descriptions of the laboratory experiments that you will be conducting throughout your studies, as well as important information about safety procedures, data collection, and report writing.

The study of civil engineering is a hands-on discipline that requires students to apply theoretical concepts to real-world problems. The laboratory experiments in this Manual will provide you with the opportunity to gain practical experience in a variety of areas, such as strength of materials, fluid mechanics, soil mechanics, structural analysis, transportation engineering, and environmental engineering.

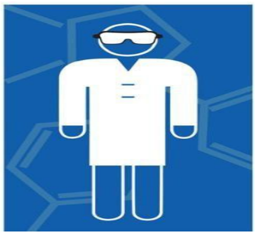
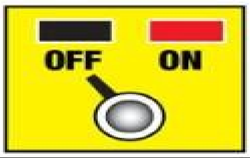
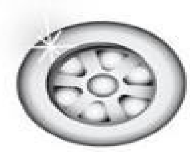
By completing these experiments, you will develop important skills such as problem-solving, critical thinking, and teamwork. You will also learn how to use a variety of laboratory equipment and how to collect and analyze data. The laboratory experience is an essential part of your civil engineering education, and this Manual will help you make the most of it.

We hope that you find this Manual to be a helpful and informative resource. Please do not hesitate to contact your instructors if you have any questions.

2. List of laboratories

No.	Name of the Laboratory
1.	STRENGTH OF MATERIAL AND CONCRETE LABORATORY
2.	SOIL MECHANICS LABORATORY
3.	FLUID MECHANICS AND HYDRAULICS LABORATORY
4.	SURVEYING LABORATORY
5.	TRAFFIC AND TRANSPORTATION LABORATORY

3. General safety guidelines

Rule	Guideline/Prohibition	Rationale
1	No Eating, Drinking, or Chewing Gum	To maintain a sterile and safe environment. 
2	No Smoking in the Laboratory Area	To safeguard the laboratory and its occupants. 
3	Dress Appropriately	Appropriate attire for personal safety and experiment integrity. 
4	Conduct Yourself Responsibly	Maintain a focused and serious atmosphere. 
5	Hazard Symbols Awareness	Identify potential dangers in the laboratory. 
6	Equipment Shutdown	Conserve energy and prevent equipment damage. 
7	Equipment Cleaning	Promote equipment longevity and prevent cross-contamination. 
8	Maintain Cleanliness	Ensure a safe, efficient, and well-maintained laboratory. 

SAFETY FIRST

(General Administration Of Safety and Risks)
الإدارة العامة للسلامة والمخاطر
Phone: 0177257700 - 15424
Email: safety@bu.edu.sa

(Important Phone Number)
ارقام مهمه

رقم التلفون	الجهة	رقم التلفون	الجهة
933	طوارئ الكهرباء Electricity Emergency	999	الشرطة Police
939	طوارئ المياه Water Emergency	998	الدفاع المدني Fire Department
937	استشارة طبية Medical advice	997	الاسعاف Red Crescent
911	الدوريات الامنيه Emergency Number	996	امن الطرق Roads Security
980	مكافحة الفساد Corruption (Nazaha)	993	المرور Traffic

Civil Engineering Department Laboratories

4. Strength of material and concrete laboratory

4.1 Introduction

A comprehensive understanding of the behavior and characteristics of structural materials such as concrete and steel can be achieved through and well-executed firsthand experience with these materials. By conducting laboratory tests, students will gain familiarity with the nature and properties of these materials.

The selected tests have been specifically chosen to highlight the fundamental properties and testing methods of cement, aggregates, paste, mortar, concrete, and steel. While certain test procedures may be simplified due to time constraints, they largely adhere to the guidelines outlined by the ASTM Standards.

4.2 Objectives

1. Equip students with the skills to effectively connect theory with practical application and demonstrate a solid understanding of theoretical concepts.
2. Train students in generating and analyzing data through experiments and enable them to apply statistical methods to the collected data.
3. Provide students with hands-on experience through experiments and give them exposure to various equipment and machinery.
4. Solve problems, including those involving design elements relevant to their coursework.
5. Promote the use of computers for data analysis among students.

4.3 Student Responsibilities

1. Before commencing laboratory work, students will be assigned to groups, and regular attendance is mandatory for this purpose.
2. Each laboratory session consists of two parts. In the first part, the instructor will deliver a lecture on the objective, procedure, and data collection of the experiment. In the second part, students, organized into groups, are required to conduct fieldwork. To make the most of the fieldwork and complete it within the designated time, students should familiarize themselves with the experiment's purpose, objective, and procedure before attending the laboratory. It is important to study relevant lecture notes and laboratory manuals carefully and thoroughly.
3. Upon completion of the experiment, each group must submit a draft sheet of the collected data for approval by the instructor.
4. It is essential to properly maintain and clean the instruments and tools during and

after each laboratory session. Additionally, students should always exercise caution to prevent potential hazards. Students must adhere to the laboratory regulations provided at the end of this section.

4.4 Report Writing

For every test conducted, each student must submit an individual report. The reports should be written on high-quality A4 paper. As a general guideline, the reports should be organized following the template as shown in **Appendix (A).**

4.5 Laboratory Regulations

1. Before commencing your experiments, ensure that you are aware of the whereabouts of the Fire Extinguishers, First Aid Kit, and Emergency Exits.
2. Promptly seek First Aid for any injury, regardless of its severity.
3. Avoid wearing loose clothing.
4. Always wear closed-toe shoes, such as safety shoes or boots.
5. Refrain from tampering with valves, screws, and nuts.
6. Obtain proper authorization and knowledge from laboratory personnel before attempting to operate any machinery.

4.6 List of Experiments as per Al-Baha University Curriculum

1. Cement Testing: The evaluation of cement involves assessing its consistency, fineness, setting time, specific gravity, soundness, and strength.
2. Fine Aggregate Testing: The examination of fine aggregate includes determining its specific gravity, conducting sieve analysis, and assessing bulk density.
3. Coarse Aggregate Testing: The analysis of coarse aggregate comprises measuring its specific gravity, conducting sieve analysis, determining bulk density, assessing flakiness index and elongation index, measuring water absorption and moisture content, and evaluating soundness.
4. Concrete Mix Design Methods: Concrete mix design can be performed using various methods such as the ACI method.
5. Concrete Testing: Tests conducted on concrete include workability assessments such as the slump cone test, compaction factor test, and flow table test. Strength tests are also conducted, including compressive strength, flexural strength, and split tensile strength evaluations.

4.7 List of Experiments of The strength of materials laboratories

No.	TEST	Apparatus
1	Tensile Test	WP 300 Universal testing machine
2	Compressive Test	WP 300 Universal testing machine
3	Torsion Test	WP 500 Torsion test, 30N.m
4	Impact Test	WP 400-Impact test, 25N.m
5	Bending Test	WP 300 Universal testing machine
6	Buckling behavior Test	WP 120 Buckling behavior of bars

MORE DETAILS IN APPENDIX (B) and APPENDIX (C)

5. Soil mechanics laboratory

5.1 Introduction

Soil is the material which supports the foundation of all structures. It is also used as a construction material for civil engineering works. Knowledge of physical and mechanical properties of soil is very important. Laboratory soil engineering courses represent an integral part of the theoretical study.

5.2 Objectives

1. Develop an understanding of the physical and mechanical properties of soil. This includes learning how to classify soil, measure its water content and density, and determine its strength and stress-strain characteristics.
2. Gain practical experience in conducting soil tests. This involves learning how to use a variety of soil testing equipment, such as hydrometers, pycnometers, and direct shear devices.
3. Apply theoretical concepts of soil mechanics to real-world problems. This may involve designing foundations, analyzing slopes, or evaluating the suitability of soil for a particular construction project.
4. Develop critical thinking and problem-solving skills. Students will need to be able to analyze their test results, draw conclusions, and make recommendations based on their findings.

5.3 Report Writing

To ensure proper documentation and individual understanding, each student will prepare and submit a personal report for every completed soil mechanics lab test. A high-quality A4 paper is mandatory for report submission. Use the report template provided in Appendix (A) as a guide when structuring your reports. This ensures consistency and adherence to key elements expected in your work.

5.4 Lab. Instrument

The soil lab allows the students to perform soil experiments. The table below indicates the soil tests.

No.	TEST	Instruments
1	Sieve analysis test	Sieves, oven, balance, and mechanical vibration machine
2	Natural water content	Drying oven set at 105°C.
3	Unconfined Compression	Unconfined compression machine
4	Constant Head Permeability	head perimeter
5	Falling Head Permeability	Constant head permeameter Graduated flask
6	Liquid limit	Casagrande device
7	Consolidation	Consolidation (Odometer)
8	Plastic limit	Glass plate, oven, and balance
9	Pocket penetrometer	Pocket device

MORE DETAILS IN APPENDIX (D)

6. Fluid Mechanics and Hydraulics Laboratory

6.1 Introduction

Fluid mechanics, the branch of science that deals with the study of fluids (liquids and gases) in a state of rest or motion, is an important subject of Civil Engineering. Its various branches are fluid statics, fluid kinematics and fluid dynamics.

The Hydraulics Course is one of the main courses at the Civil Engineering Department of Al-Baha University. The course is concerned with the practical applications of fluids, primarily water, in motion. The objective of the course is to enable students to design the components of closed and open conduits water systems such as transmission lines, pumping station, and open channels; and to select suitable hydraulic machines such as pumps and turbines based on the hydraulic design. Besides the theoretical part of the courses, the students are qualified to perform selected lab experiments. the laboratory exercises outlined here are designed to assist the student in the investigation of fluid properties, application of flow measurement techniques, application of conservation laws, pipe and open channel flow.

6.2 Objectives

1. Investigate Fluid Properties: Students will delve into the heart of fluids by exploring properties like viscosity, density, and surface tension through hands-on experiments. This provides crucial insights into how fluids behave in different scenarios.
2. Master Flow Measurement Techniques: Learning is not just theoretical; students will gain practical mastery in measuring flow rates using diverse techniques like weirs, flumes, and flow meters. This equips them for real-world applications involving water management and design.
3. Apply Conservation Laws in Practice: Conservation principles, like continuity and momentum, underpin fluid mechanics. The lab provides a platform to translate these theories into tangible experiences. Students will witness firsthand how these laws govern fluid behavior in various setups.
4. Explore Pipe and Open Channel Flow: Analyzing water movement in both confined pipes and open channels is fundamental to hydraulic engineering.

Through experiments, students gain a firsthand understanding of factors like head loss, friction, and channel characteristics, enabling them to design and analyze such systems effectively.

6.3 Report Writing

Use the report template provided in Appendix (A) as a guide.

6.4 Lab. Instrument

The lab allows the students to perform the experiments outlined in the course specification. The equipment used is listed in the Table and figures below.

Condition	Quantity	اسم الصنف		م
		باللغة الإنجليزية	باللغة العربية	
Excellent	1	Properties of fluids and hydrostatics bench	طاولة معملية لقياس خواص الموائع	1
Excellent	3	Basic hydraulic bench	طاولات معملية هيدروليكية أساسية	2
Excellent	1	Bernoulli’s principle demonstrator	جهاز فنشوري(للتحقق من معادلة برنولي)	3
Excellent	1	Losses in bends and fittings	جهاز احتكاك السوائل(لقياس الفاقد الثانوية في الأنابيب)	4
Excellent	1	Flow visualization apparatus	جهاز نظر للسيلان (للتحقق من أنواع السريان)	5
Excellent	1	Orifice and jet velocity apparatus	جهاز التدفق عبر الفوهات(يركب على الطاولة في بند1)	6
Excellent	1	Impact of jet apparatus	جهاز اثر قوى الدفع على الأسطح المختلفة	7
Excellent	1	Flow channel	جهاز السريان عبر القنوات المفتوحة	8
Excellent	1	Potential flow	جهاز تدفق الجهد	9
Excellent	1	Drainage and seepage tank	حوض دراسة الصرف والتسرب	10
Excellent	1	Advanced hydrology system	وحدة متقدمة للدراسات الهيدرولوجية	11
Excellent	1	Rainfall hydrograph unit	وحدة دراسات سقوط الأمطار	12
Excellent	5	Experimental benches 180*90*80 cm with electrical	طاولة مختبر مقاس 180*90*80سم	13
Excellent	20	Student chair	كرسي طالب	14
Excellent	3	Cabinet for storing devices	خزانة لحفظ الأجهزة مقاس 120*80*60سم(مرتبطة بالطاولة في بند	15

Properties of fluids and hydrostatics bench (GUNT-HM 115)

Basic hydraulic bench (GUNT-HM 150)

Bernoulli’s principle demonstrator (GUNT-HM 150.07)

Losses in bends and fittings (GUNT-HM 150.29)

Flow visualization apparatus (GUNT-HM 150.10)

Orifice and jet velocity apparatus (GUNT-HM 150.09)

Impact of jet apparatus (GUNT-HM 150.08)

Flow channel (GUNT-HM 150.21)

Potential flow (GUNT-HM 152)

Drainage and Seepage Tank (GUNT-HM 169)

Advance Hydrology System (GUNT-HM 145)

Rainfall Hydrograph Unit (GUNT-HM 141)

6.5 Experiment Name, Tools, and Equipment

Item No.	Experiment(s) Name	Tools & Equipment
1	Determination of Discharge	Base module for experiments in fluid mechanics
2	Pressure distribution along an effective area in a liquid at rest • lateral force of the hydrostatic pressure • determination of the center of pressure and center of area • determination of the resulting compressive force	Properties of Fluids, Hydrostatic pressure in liquids and Hydraulic Bench

Item No.	Experiment(s) Name	Tools & Equipment
3	• How differently shaped weirs affect the flow • Determining the discharge coefficient • Comparison of measuring weirs • Free over fall at the sharp-crested weir	Control Structures: Plate weirs
4	Energy conversion in divergent/convergent pipe flow • recording the pressure curve in a Venturi nozzle • recording the velocity curve in a Venturi nozzle	Bernoulli's principle
5	• study of the jet forces • study of the outlet jet (diameter, velocity) letermine pressure losses and contraction coefficient for different outlet contours	Measurement of jet forces
6	• influence of flow rate, flow velocity and different deflection angles • recording the trajectory of the water jet at different outlet velocities • determination of the contraction coefficient for different contours and diameters • • streamlines in flow around drag bodies and flow through changes in cross-section	Orifice &jet velocity apparatus
7	• visualization of streamlines for flow incident to a weir • visualization of streamlines when flowing around various drag bodies	Visualization of streamlines
8	• pressure losses in pipes, piping elements and fittings how the flow velocity affects the pressure loss determining resistance coefficients	Losses in a pipe system
9	isualization of streamlines in an open channel around different shapes of bodies	Visualization of streamlines in an open channel
10	• investigate pressure losses at segment bend and bends • investigate pressure loss at contraction and enlargement • pressure loss at a ball valve and determination of a simple valve characteristic	Energy losses in piping elements
11	effect of rainfall of varying duration on the discharge • storage capacity of a soil • investigating steady processes • seepage flow • effects of wells on the groundwater level over time	Advanced hydrological investigations
12	Hele-Shaw cell with screening in the bottom glass panel for optimal observation of the streamlines • two-dimensional, in viscid potential flows • influence of sources and sinks on the streamlines • various models: drag bodies and changes in cross-section	Potential flow
13	Simulation of rainfall and determination of the rainfall hydrograph	Rainfall hydrograph unit

MORE DETAILS IN APPENDIX (E)

7. Surveying Laboratory

7.1 Introduction

Traditionally, surveying concerned with making some sort of measurement to determine the location of points to produce maps, or layout such point, surveying can be related to all civil engineering branches such as building, road engineering, water resources, irrigation, drainage engineering … etc. in all steps of data acquisition and planning, designing, execution, and monitoring. Laboratory component of surveying engineering courses represents an integral part of the theoretical component. It relates theory with practice. It gives the students a valuable chance to do a real job. Moreover, it gives the students the self-confidence to work in the field. In addition to that, it assists students to improve their skills in teamwork and leadership skills.

7.2 Objectives

1. Develop practical surveying skills: The lab emphasizes hands-on experience, allowing students to learn and practice various surveying techniques beyond theory. This includes using equipment, conducting measurements, and applying learned concepts in real-world scenarios.
2. Reinforce theoretical understanding: By actively engaging in practical exercises, students gain a deeper understanding of surveying principles and how they translate into actual fieldwork. This reinforces classroom learning and strengthens their grasp of key concepts.
3. Prepare for diverse civil engineering applications: Surveying plays a crucial role across various civil engineering branches. The lab exposes students to how these skills are applied in different contexts, like building construction, road design, water resource management, and irrigation projects. This broadens their perspective and prepares them for future specialization.
4. Cultivate essential professional skills: Beyond technical knowledge, the lab fosters soft skills like teamwork and leadership. Working together on Surveying projects and taking initiative in different aspects contribute to their professional development and prepare them for collaborative work environments.

7.3 Report Writing

Use the report template provided in Appendix (A) as a guide.

7.4 Lab. Instrument

Recently, new surveying instruments have been added to the surveying lab. Now, the surveying Lab consists of all necessary instruments required to achieve surveying course experiments including tapes, poles, compasses, theodolites, levels, and handheld GPS. In addition to other accessories. Table Below represents classification of surveying lab instruments.

No.	Instrument	Description	Quantity
1	Theodolite	Digital Theodolite	2
2	Level	Automatic Level	3
3	Levelling Rod	Aluminum Grad Rod	4
4	Tripod	Surveying Tripod	4
5	Tape	Fiberglass Tape (LAND 50m LD-159)	4
6	Reflector	Single Prizm Reflector (GPH1)	1
7	Compass	Prismatic Compass	2
8	handheld GPS	Garmin	1
9	Measuring wheel	-	1
10	Distometer	-	1

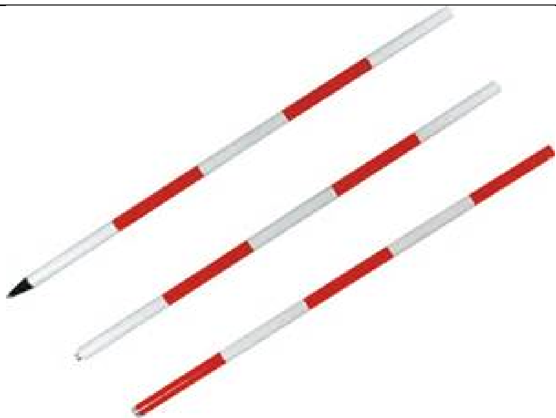
7.5 Lab. Experiments

Throughout this semester, students had a chance to do the following eight experiments:

1. Temporary adjustment of the level including Levelling and Parallax elimination.
2. Differential levelling and series levelling.
3. Applying the Stadia system as a sample of O.D.M.
4. Taking linear measurements using tape.
5. Theodolite temporary adjustment, including Centering, Levelling, and Parallax elimination.
6. Measuring horizontal angles.
7. Measuring vertical angles.
8. Setting out circular curves using tape.

MORE DETAILS IN APPENDIX (F)

7.6 surveying instruments

Item	Instrument	Figure
1	Steel Tape	
2	Ranging Rods	
3	Compass	
4	Optical Level	

Item	Instrument	Figure
5	Digital Theodolite	
6	Distometer	
7	Handheld GPS	
8	Measuring Wheel	

8. Traffic and transportation laboratory

8.1 Introduction

The traffic and transportation lab is one of the main labs at the Civil Engineering Department of Al-Baha University. The lab is concerned with the characteristics of highway materials including soil, aggregate, asphalt, and hot asphalt mixes. The main objective of this lab is to enable students to critically evaluate the characteristics of highway materials by running the appropriate experimentation and designing the flexible pavement structure. The laboratory of highway material represents an integral part of the theoretical component of the course of highway material and pavement design. It gives the students the chance to run the experiments by themself and gain self-confidence to work in the field.

8.2 Objectives

1. To enable students to critically evaluate the characteristics of highway materials: This is done through a variety of hands-on experiments, such as tests for the basic properties of asphalt, soil, and aggregate, as well as the design of hot mixes asphalt.
2. To provide students with the necessary skills to run the needed tests, interpret results, and extract the basic inputs required for flexible pavement design.
3. To prepare students for careers in civil engineering: The skills and knowledge that students gain in the lab are essential for a career in civil engineering, particularly in the areas of transportation and pavement design.
4. To contribute to the development of the transportation infrastructure in Saudi Arabia: By training the next generation of civil engineers, the lab is helping to ensure that Saudi Arabia has the infrastructure it needs to support its growing population and economy.

8.3 Report Writing and Grade Distribution

Use the report template provided in Appendix (A) as a guide. The distribution of lab report grades will be as follow:

Part of the Report	Weight (%)
Summary	5
Introduction and objectives	15
Methodology	15
Test results	15
Analysis, Discussion and Conclusions	40
References	5
Neat Production	5
TOTAL	100

Notes:

1. Absolutely no late reports are accepted.
2. A bonus is expected for a well-prepared report and for any extra put effort.
3. Failure to attend the lab meeting implies missing the chance to submit the report required for this session.

8.4 Lab. Experiments

The following table presents a list of the experiments needed for the course of Structural Pavement Design along with brief objectives. The detail test procedures can be obtained from standard test methods (either ASTM or AASHTO) mentioned in the last column in the next table. The details of these tests are also presented in the following table.

Name of Experiment	Objectives	Procedures According to:
Standard compaction test or Modified compaction test	To find the optimum water content and max dry density of the compacted soil.	• AASHTO T-99 or ASTM D698 • AASHTO T-180 or ASTM D1557
California Bearing ratio.	CBR is used to evaluate the performance of soil mainly used as a bases, sub-bases and subgrades beneath of roads and airfields.	AASHTO T-193 or ASTM D1883
Field density by sand cone.	To evaluate the quality of field compaction by finding the field dry density and compare it to Lab max dry density to determine the DOC.	AASHTO T-191 or ASTM D1556
Specific gravity and absorption test for course aggregate.	To find the bulk and apparent specific gravity of aggregate along with percent of absorption.	AASHTO T-85 or ASTM C127

Name of Experiment	Objectives	Procedures According to:
Abrasion test for aggregate by Los Angeles machine.	To evaluate the performance of aggregate against toughness and abrasion resistance.	AASHTO T-96 or ASTM C131
Soundness of aggregate.	To determine the aggregate's resistance to disintegration by weathering and, in particular, freeze-thaw cycles.	AASHTO T-104 or ASTM C88
Penetration test for asphalt cement.	Used to measure consistency of bituminous materials under specific conditions of loading, testing time and temperature.	ASHTO T-49 or ASTM D5
Softening point (ring and ball) test for asphalt cement.	The main objective is to measure and specify the temperature at which bituminous binders begin to show fluidity. It is also a measure of consistency for air-blown asphalt.	AASHTO T-53 or ASTM D36
Saybolt viscosity for liquid asphalt.	To determining saybolt viscosity of petroleum products at specified temperature.	AASHTO T-72 or ASTM D88
Flash and fire point by Cleveland open cup.	• To determine the flash and fire points of all petroleum products, except fuel oils and materials having	AASHTO T-48 or ASTM D92

Name of Experiment	Objectives	Procedures According to:
	an expected flash point below 79 ◦C. • The flash and fire points indicate the materials combustibility.	
Marshall mix design:	The objective of Marshall Mix design procedure is to find the optimum binder content in the mix.	
Preparation of asphalt mixture specimens using Marshall apparatus.	As mentioned above	ASTM D 6926 -16
Bulk Specific Gravity Determination Gmb	As mentioned above	ASTM D 2726
Stability and flow test for compacted asphalt mixture.	As mentioned above	AASHTO T-245 or ASTM D5581
Maximum specific gravity test for loss asphalt mixture.	As mentioned above	AASHTO T-209 or ASTM D2041

MORE DETAILS IN APPENDIX (G)

Appendixes

Writing lab Report Template

Albaha University
Faculty of Engineering
Civil Engineering Department

Course # (……..)
Course Title : ……………………….
Semester : (…………………)

Instructor : …………………………….

Group ….

Experiment No. …….
Title of Experiment: …………………….

Names	ID.s
1.	

Date of Experiment: …………………
Time of Experiment……………………………

Table of contents

Team meeting (Optional)

Introduction

Experimental design

Data

Calculations

Figures & Graphs

Results & Discussion

References

(Optional)

Meeting Minutes

Meeting#.. of Rport#..

Time: …….

Date: …….

Venue: ……………….

Attendants:

1) ……………………….
2) ………………………..
3) ……………………….
4) ………………………..

Agenda

Writing tasks that are taken before and during the meeting.

Discussion Taken

Writing down all objectives you will discuss in the meeting.

Actions Person Responsible

Writing the distribution of tasks between team members.

Introduction:

Usually, the Introduction is one paragraph that **explains the objectives or purpose of the lab**. In one sentence, state the hypothesis. Sometimes an introduction may contain background information, briefly **summarize how the experiment was performed**, state the findings of the experiment, and list the conclusions of the investigation. Even if you don't write a whole introduction, you need to state the purpose of the experiment, or why you did it. This would be where you state your hypothesis.

Experimental design

a) Materials

List everything needed to complete your experiment.

b) Equipments:

List everything needed to complete your experiment.

c) Methods

Describe the steps you took during your investigation. This is your procedure. Be sufficiently detailed that anyone could read this section and duplicate your experiment. Write it as if you were giving directions for someone else to do the lab. It may be helpful to provide a Figure to diagram your experimental setup.

Data:

Numerical data obtained from your procedure usually is presented as a table. Data encompasses what you recorded when you conducted the experiment. It's just the facts, not any interpretation of what they mean.

Calculations:

The Analysis section contains **any calculations you made based on those numbers**. This is where you interpret the data and determine whether or not a hypothesis was accepted.

Figures & Graphs

Graphs and figures must both be labeled with a descriptive title. Label the axes on a graph, being sure to include units of measurement.

Results & Discussion

Describe in words what the data means. Sometimes the Results section is combined with the Discussion (Results & Discussion).

Reference:

If your research was based on someone else's work or if you cited facts that require documentation, then you should list these references.

Experiments described as per Al-Baha University Curriculum for Concrete laboratory.

Experiment No. **: 01(a)** **Date**

Title **: Determination of Consistency of Standard Cement Paste**

Objective: To determine the normal consistency of a given sample of cement.

Theory:

To determine the initial setting time, final setting time, soundness, and strength of cement, it is necessary to utilize a parameter called standard consistency. The standard consistency of a cement paste is defined as the consistency at which a Vicat plunger with a diameter of 10 mm and a length of 50 mm can penetrate to a depth of 33-35 mm from the top of the mold.

Apparatus:

Vicat apparatus, Balance, Gauging Trowel, Stopwatch, etc.

Procedure:

1) The standard consistency of a cement paste is the desired thickness that allows the Vicat plunger to penetrate to a depth of 5 to 7 mm from the bottom of the Vicat mold.

2) Initially, take a cement sample weighing approximately 300 g and mix it with a specific percentage of water based on the weight of the cement. Start with 26% water and increase it by 2% increments until the normal consistency is reached.

3) To prepare the paste, combine 300 g of cement with a measured amount of potable or distilled water. Take care to gauge the mixture for a minimum of 3 minutes and a maximum of 5 minutes, ensuring that no signs of setting occur before gauging is complete. The gauging time should be counted from the moment water is added to the dry cement until the mold is filled.

4) Fill the Vicat mold (E) with the prepared paste, ensuring that the mold is placed on a non-porous plate. After filling the mold, level the surface of the paste with the top of the mold, smoothing it out. You may gently shake the mold to remove any trapped air.

5) Position the test block and the non-porous plate inside the mold, beneath the rod that holds the plunger. Lower the plunger gently until it touches the surface of the test block, and then release it quickly, allowing it to sink into the paste. This step should be performed immediately after filling the mold.

6) Repeat the process of preparing trial pastes with varying percentages of water and conducting the test as described above until you determine the precise amount of water needed to achieve the standard consistency defined in Step 1.

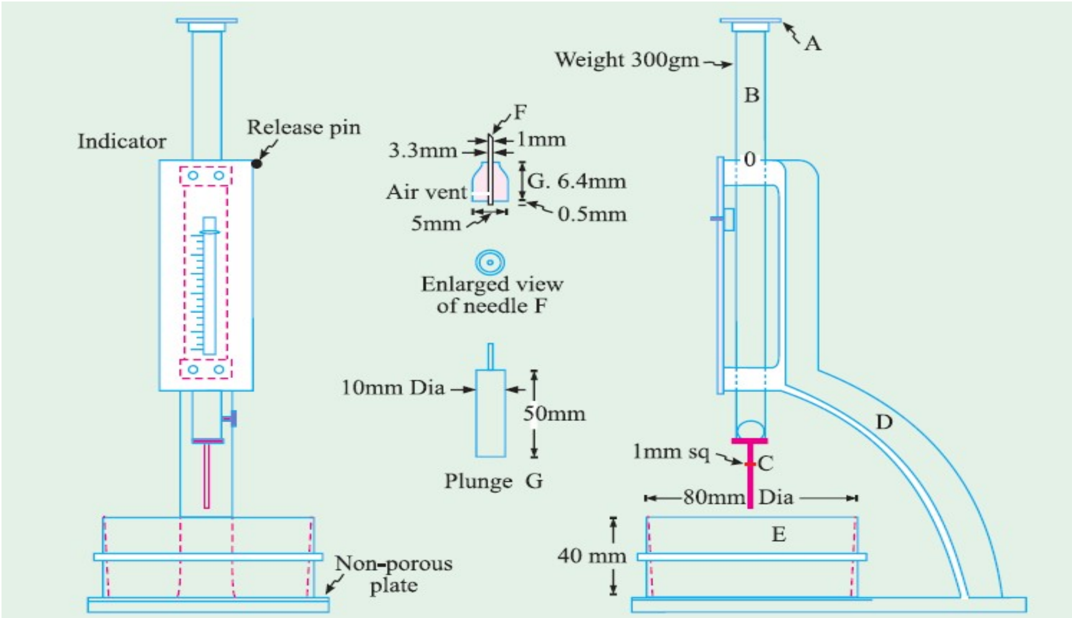


Figure 1: Vicat apparatus.

Observation:

Express the amount of water as a percentage by mass of the dry cement to the first place of decimal.

Sr. No.	Weight of cement (gms)	Percentage by water of dry Cement (%)	Amount of water added (ml)	Penetration (mm)
1				
2				
3				
4				

Conclusion / R:

The normal consistency of a given sample of cement is _ _ _ _ %

Experiment No. : 1(b) Date

Title: **Determination of Setting Time of Standard Cement Paste**

Objective: To determine the initial and final setting time of a given sample of cement.

Theory :

For convenience, initial setting time is regarded as the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between the moment the water is added to the cement and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.

Apparatus :

Vicat apparatus, Balance, Gauging Trowel, Stopwatch, etc.

Procedure

1) Prepare a clean 300-gram cement paste by mixing the cement with 0.85 times the amount of water needed to achieve a standard consistency. Use potable or distilled water for the paste preparation.
2) Begin timing as soon as the water is added to the cement. Fill the Vicat mold with the prepared cement paste, ensuring that the mold is placed on a nonporous plate. Fill the mold and smooth the surface of the paste to make it level with the top of the mold.
3) Immediately after molding, place the test block in a moist closet or moist room. Keep it there, except when determining the setting time.
4) Determining the Initial Setting Time: Position the test block, still in the mold and resting on the non-porous plate, under the rod that holds the needle (C). Lower the needle gently until it touches the surface of the test block, and then quickly release it, allowing it to penetrate the block.
5) Repeat this process until the needle, when brought into contact with the test block and released as described above, fails to pierce the block beyond 5.0 ± 0.5 mm from the bottom of the mold. This measurement represents the initial setting time.
6) Determining the Final Setting Time: Replace the needle (C) of the Vicat apparatus with the needle that has an annular attachment (F).
7) The cement is considered finally set when, upon gently applying the needle to the surface of the test block, the needle leaves an impression while the attachment does not.

8) The time elapsed between adding water to the cement and the moment when the needle leaves an impression on the test block, while the attachment does not, is the final setting time.

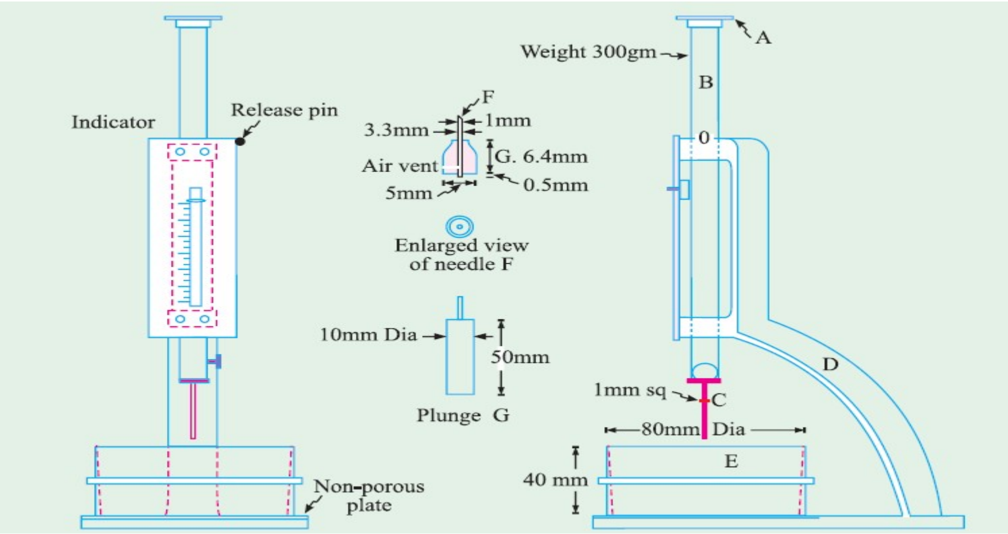


Figure 2: Vicat apparatus

Observation :

The weight of a given sample of cement is _ _ _ _ gms

The normal consistency of a given sample of cement is _ _ _ _ %

The volume of water added (0.85 times the water required to give a paste of standard consistency) for preparation of test block _ _ _ _ ml

Sr. No.	Setting Time (Sec)	Penetration (mm)	Remark
1			
2			
3			

Conclusion / Result:

- The initial setting time of the cement sample is found to be …..
- The final setting time of the cement sample is found to be …..

Experiment No.	**:**	**01(c)**	**Date**
Title	**:**	**Determination of Fineness of Cement by dry sieving**	

Objective: To determine the normal consistency of a given sample of cement.

Theory :

The level of fineness in cement plays a crucial role in the speed of hydration, which in turn affects the rate of strength gain and heat evolution. When cement is finely ground, it offers a larger surface area for hydration, leading to faster strength development (see Figure 3). Over the years, there has been an increase in the fineness of grinding, but it has now reached a point of stability. Different types of cement are ground to varying degrees of fineness. Among these, the particle size fraction below 3 microns has the most significant impact on the strength after one day, while the 3–25-micron fraction greatly influences the strength after 28 days. Additionally, an increase in cement fineness has been observed to cause higher drying shrinkage in concrete.

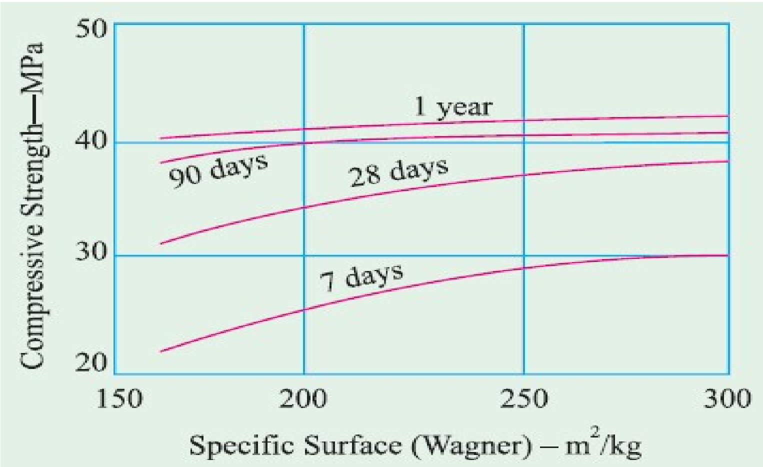


Figure 3:

The fineness of cement is tested in two ways :

a) By sieving.

b) By determination of specific surface (total surface area of all the particles in one gram of cement) by air-permeability apparatus. Expressed as cm^2/gm or m^2/kg. Generally, the Blaine Air permeability apparatus is used.

Apparatus: Test Sieve 90 microns, Balance, Gauging Trowel, Brush, etc.

Procedure :

1) Place the tray beneath the sieve and accurately measure approximately 10 grams of cement, ensuring the measurement is precise to the nearest 0.01 grams. Carefully place the measured cement on the sieve, taking precautions to prevent any loss. Securely attach the lid to the sieve. Agitate the sieve using swirling, planetary, and linear movements until there is no further passage of fine material through it.

2) Take out the sieve and measure the remaining residue. Express the mass of the residue as a percentage, denoted as R1, relative to the initial quantity placed on the sieve, rounded to the nearest 0.1 percent. Gently brush off all the fine material from the base of the sieve into the tray.

3) Repeat the entire process using a fresh 10-gram sample to obtain R2. Then calculate the residue of the cement, denoted as R, as the average of R1 and R2, expressed as a percentage and rounded to the nearest 0.1 percent.

4) If the results differ by more than 1 percent absolute, perform a third sieving and calculate the mean of the three values.

Conclusion / R: The fineness of a given sample of cement is _ _ _ _ %

Experiment No. : **01(d)** **Date**

Title : **Determination of Soundness of Cement by Le-Chatelier method**

Objective: To determine the soundness of a given sample of cement by the Le-Chatelier method.

Theory :

It is important to ensure that cement does not experience significant volume changes after it has been set. Certain types of cement have been found to undergo substantial expansion after setting, which can disrupt the hardened mass. This poses serious durability issues for structures constructed using such cement. The unsoundness of cement is typically attributed to the presence of excessive lime, which can react with acidic oxides during the kiln process. Additionally, high levels of magnesium or calcium sulphate content can also contribute to unsoundness in cement. The soundness of cement can be assessed using two methods: the Le-Chatelier method and the autoclave method.

Apparatus :

Le- Chatelier test apparatus, Balance, Gauging Trowel, Water Bath, etc.

Procedure :

1) Place the mold, lightly coated with oil, onto a glass sheet that has also been lightly oiled. Fill the mold with a cement paste created by mixing cement with 0.78 times the amount of water necessary to achieve a standard consistency paste.
2) The paste should be mixed according to the procedures and conditions outlined in experiment No.1. Take care to keep the edges of the mold gently pressed together during this process.
3) Cover the mold with another oiled glass sheet and place a small weight on top of the cover. Immediately submerge the entire assembly in water at a temperature of 27 ± 2°C and leave it submerged for 24 hours.
4) Measure the distance between the indicator points, rounding to the nearest 0.5 mm. Once again, submerge the mold in water at the specified temperature.
5) Maintain the submerged mold in boiling water for 25 to 30 minutes and continue boiling it for three hours. Remove the mold from the water, allow it to cool, and measure the distance between the indicator points.

6) The difference between these two measurements indicates the expansion of the cement. For ordinary, rapid hardening, and low-heat Portland cement, this expansion must not exceed 10 mm. If the expansion exceeds 10 mm, as determined by the above test, the cement is considered unsound.

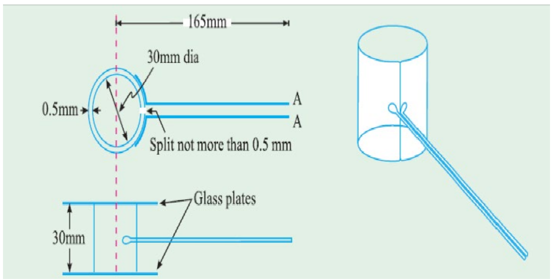


Figure 4 : Le- Chatelier test apparatus.

Observation :

Sr. No.	The distance separating the indicator submerged in normal temp water for 24 hours	Distances separating the indicator submerge in boiling for three hours.	The difference between these two measurements	Remark
1				
2				
3				
4				

Express the amount of water as a percentage by mass of the dry cement to the first place of decimal.

Conclusion / R: The given cement is said to be sound/unsound.

Experiment No. : 01(d) Date

Title : Determination of Compressive Strength of Cement

Objective: To determine the compressive strength of a given sample of cement.

Theory :

The compressive strength of hardened cement is the most important of all the properties. Therefore, it is not surprising that the cement is always tested for its strength at the laboratory before the cement is used in important works. Strength tests are not made on neat cement paste because of the difficulties of excessive shrinkage and subsequent cracking of neat cement.

Apparatus :

The standard sand to be used in the test, Vibration Machine, Poking Rod, Cube Mould of 70.6 mm size, Balance, Gauging Trowel, Stopwatch, Graduated Glass Cylinders, etc.

Procedure :

1) Test Specimen Preparation - Use clean equipment for mixing. The temperature of the water and the test room during these operations should be maintained at 27 ± 2°C. Utilize potable or distilled water when preparing the cubes.
2) Each cube's materials should be mixed separately, and the quantities of cement, standard sand, and water should meet the following requirements: 200 g of cement, 600 g of standard sand, and water equivalent to ((P/4)+3.0) percent of the combined mass of cement and sand. Here, P represents the percentage of water needed to create a paste of standard consistency.
3) On a nonporous plate, place a mixture of cement and standard sand. Dry mix it with a trowel for one minute, and then add water until the mixture achieves a uniform color. The amount of water used should adhere to the specifications mentioned in Step 2. The mixing time should be a minimum of 3 minutes. If it takes more than 4 minutes to obtain a uniform color, reject the mixture and repeat the process with fresh quantities of cement, sand, and water.
4) Specimen Moulding - When assembling the molds for use, apply a thin coating of mold oil to the interior faces of the molds.
5) Position the assembled mold on the vibration machine's table and secure it firmly using an appropriate clamp. Attach a hopper of suitable size and shape securely to the top of the mold to facilitate filling. The hopper should remain in place until the vibration period is complete.

6) Immediately after mixing the mortar according to steps 1 and 2, place the mortar in the cube mold and compact it by prodding it with a rod. Fill the mortar into the hopper of the cube mold, prod it again as specified for the first layer, and then compact the mortar through vibration.

7) The vibration should continue for two minutes at a specified speed of 12000 ± 400 vibrations per minute.

8) After the vibration, remove the mold, along with the base plate, from the machine. Finish the top surface of the cube within the mold by smoothing it with the blade of a trowel.

9) Specimen Curing - Place the filled molds in a moist closet or moist room for 24 ± 1 hour after completing the vibration. After this period, remove the specimens from the molds and immediately submerge them in clean, fresh water. Keep the specimens submerged until just before breaking, ensuring they do not dry out.

10) The water in which the cubes are submerged should be replaced every 7 days and maintained at a temperature of 27 ± 2°C. While they are out of the water but not yet broken, prevent the cubes from drying.

11) Test three cubes for compressive strength at each specified curing period (i.e., 3 days, 7 days, 28 days) as indicated in the relevant specifications.

12) The cubes should be tested in a sideways position, without any packing between the cube and the steel platens of the testing machine. One of the platens should be carried on a base and be self-adjusted. Apply the load steadily and uniformly, starting from zero at a rate of 35 N/mm2/min.

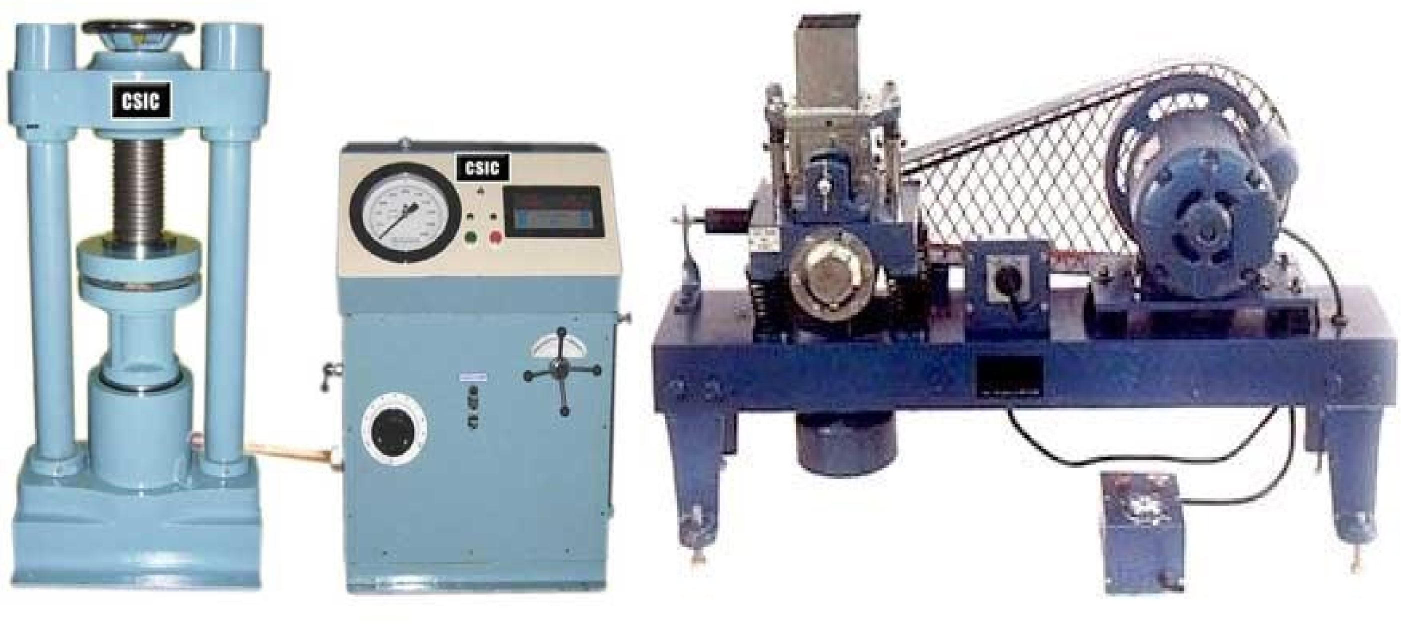


Figure 5: Compression Testing Machine.

Observation :

Sr. No.	Age of Cube	Weight of Cement Cube (gms)	Cross-Sectional area (mm^2)	Load (N)	Compressive strength (N/mm^2)	Average Compressive strength (MPa)
1	3Days					
2						
3						
4	7 Days					
5			`			
6						
7	28 Days					
8						
9						

Calculation :

The compressive strength of the cubes will be determined by dividing the maximum load applied during the test by the cross-sectional area, which is calculated based on the average dimensions of the section. The resulting value will be rounded to the nearest 0.5 N/mm_2. Any specimens that are visibly flawed or have strengths deviating by more than 10 percent from the average value of all the test specimens should not be included when determining the compressive strength.

Conclusion / Result :

The average 3-day compressive Strength of a given cement sample is found to be ……….
The average 7-day compressive Strength of a given cement sample is found to be ……….
The average 28-day compressive Strength of the given cement sample is found to be ……….

Experiment No. : **02(a)** **Date**

Title : **Particle Size Distribution of Fine Aggregates**

Objective: To determine the fineness modulus of fine aggregate and classifications
Theory:

Sieve analysis refers to the process of dividing a sample of aggregate into different fractions, each consisting of particles of the same size. Its purpose is to determine the particle size distribution, known as gradation, in the aggregate sample. Sometimes, fine aggregates are categorized as coarse sand, medium sand, and fine sand, but these classifications lack precision. What is labeled as fine sand by a supplier might be medium or even coarse sand. To eliminate this ambiguity, the fineness modulus can be used as a measure to indicate the fineness of sand.

To provide some guidance, the following limits can be considered:

Fine sand: Fineness Modulus: **2.2 - 2.6**

Medium sand: Fineness Modulus: **2.6 - 2.9**

Coarse sand: Fineness Modulus: **2.9 - 3.2**

Sand with a fineness modulus exceeding 3.2 would be unsuitable for producing satisfactory concrete.

Apparatus:

Test Sieves of 4.75 mm, 2.36 mm, 1.18 mm, 600-micron, 300-micron, 150-micron, Balance, Gauging Trowel, Stopwatch, etc.
Procedure:

1) Before weighing and sieving, it is necessary to ensure that the sample is air-dried. The air-dried sample should then be successively weighed and sieved using the appropriate sieves, starting with the largest one. It is important to make sure that the sieves are clean before using them.

2) The shaking process should involve a varied motion, including backward and forward, left to right, circular clockwise, and anti-clockwise movements. Frequent jarring should also be applied to keep the material in constant motion over the sieve surface, changing directions frequently.

3) It is important not to apply hand pressure to force the material through the sieve. If there are any lumps of fine material, they can be gently broken by applying slight pressure with the fingers against the side of the sieve.

4) To prevent the powder from aggregating and the apertures from getting clogged, a fine camel hairbrush can be lightly brushed on the 150-micron and 75-micron sieves.

5) Once the sieving process is completed, the material that remains on each sieve, along with any material that has been cleaned from the mesh, should be weighed.

Observation:

Sieve size	Weight Retained on Sieve (gms)	Percentage of Weight Retained (%)	Percentage of Weight Passing (%)	Cumulative Percentage of Passing (%)	Remark
4.75 mm					
2.36 mm					
1.18 mm					
600 micron					
300 micron					
150 micron					
Total					

Calculation:

The fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 4.75 mm to 150 microns and dividing this sum by an arbitrary number of 100.

Fineness modulus, **FM= [(Total of cumulative percent of passing %)/100]**

Conclusion / Result:

The fineness modulus of a given sample of fine aggregate is …….. which indicates Coarse sand/ Medium sand/ Fine sand. ii) The given sample of fine aggregate is belonged to Grading Zones I / II / III / IV

Table 1: Grading limits of fine aggregates IS: 383-1970

I.S. Sieve Designation	Percentage passing by weight for			
	Grading Zone I	*Grading Zone II*	*Grading Zone III*	*Grading Zone IV*
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–70	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15

Experiment No. : **02(b)** **Date**

Title : **Determination of specific gravity in Fine Aggregate**

Objective: To determine the specific gravity of a given sample of fine aggregate.

Apparatus:

Pycnometer, A 1,000-ml measuring cylinder, well-ventilated oven, Taping rod, Filter papers and funnel, etc.

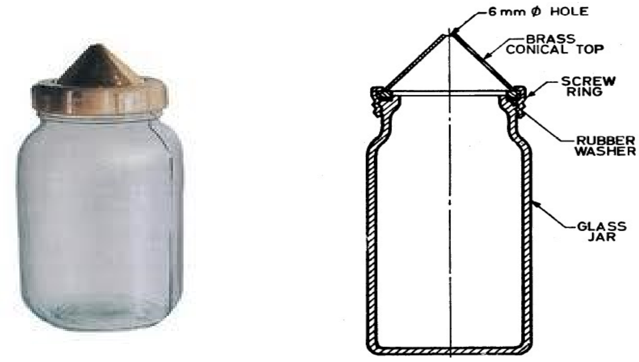


Figure 6: Pycnometer Apparatus.

Procedure:

1) Approximately 500 grams of the specimen should be placed in a tray and covered with distilled water within a temperature range of 22 to 32°C. To remove any trapped air or bubbles on the aggregate's surface, gently stir the sample with a rod. The sample should remain immersed for a period of 24 ± 1/2 hours.

2) Next, carefully drain the water from the sample by pouring it out through a filter paper, ensuring that any retained material is returned to the sample. The fine aggregate, along with any solid matter left on the filter paper, should be exposed to a mild stream of warm air until surface moisture evaporates and the material reaches a flowing consistency. Weigh the saturated and surface-dry samples (weight A).

3) Transfer the aggregate to a pycnometer and fill it with distilled water. Remove any trapped air by rotating the pycnometer on its side while covering the hole at the apex of the cone with a finger. Dry the outside of the pycnometer and weigh it (weight B).

4) Empty the contents of the pycnometer back into the tray, ensuring that all the material is transferred.

5) Carefully drain the water from the sample by decanting it through filter paper, returning any retained material to the sample. Place the sample in a tray and place it in an oven at a temperature of 100 to 110°C for approximately 24 ± 1/2 hours. Stir the sample occasionally during this period to aid in the drying process. Once dried, cool the sample in an airtight container and weigh it (weight D).

6) Perform the following calculations to determine the specific gravity, apparent specific gravity, and water absorption:

[Provide calculation instructions here].

$$\text{Specifc Gravity } = \left(\frac{D}{A-(B-C)} \right)$$

$$\text{Apparent Specifc Gravity } = \left(\frac{D}{D-(B-C)} \right)$$

$$\text{Water Absorption } = \frac{100(A-D)}{D}$$

- A= weight in g of saturated surface-dry sample,
- B= weight in g of pycnometer or gas jar containing sample and filled with distilled water,
- C= weight in g of pycnometer or gas jar filled with distilled water only, and
- D= weight in g of oven-dried sample.

Conclusion / Result:

1. The Specific Gravity of a given sample of fine aggregate is found to be …….
2. The Water Absorption of a given sample of fine aggregate is found to be ……. %

Experiment No. : **03 (a)** **Date**

Title : **Determination of Specific Gravity of Course Aggregate**

Objective: To determine the specific gravity of a given sample of course aggregate.

Apparatus:

Some items required include a wire basket with a mesh size no greater than 6-3 mm, a sturdy container that is waterproof and allows the basket to hang freely, a well-ventilated oven, a taping rod, and an airtight container of similar capacity to the basket.

Figure 6: Specific Gravity of Course Aggregate Apparatus.

Procedure:

1) The aggregate sample should weigh at least **2000 g**. It should be thoroughly washed to remove finer particles and dust drained, and then placed in a wire basket. The basket, along with the aggregate, should be immersed in distilled water at a temperature ranging from 22°C to 32°C. The water level should be at least 5 cm above the top of the basket.

2) Immediately after immersing the sample, any trapped air should be removed. This can be done by lifting the basket, containing the sample, 25 mm above the base of the tank, and allowing it to drop 25 times at a rate of approximately one drop per second. It is important to keep the basket and aggregate fully submerged during this process and for a period of 24 ± l/2 hours thereafter.

3) Next, the basket and sample should be jolted and weighed in water at a temperature between 22°C to 32°C (weight $\mathbf{A_1}$).

4) After weighing, the basket and aggregate should be taken out of the water and allowed to drain for a few minutes. Then, the aggregate should be gently emptied from the basket onto a dry cloth. The empty basket should be returned to the water and weighed in water (weight $\mathbf{A_2}$).

5) The aggregate on the dry cloth should be gently surface-dried using the cloth. If the first cloth does not remove any further moisture, the aggregate should be transferred to a second dry cloth. After surface drying, the aggregate should be weighed (weight **B**).

6) The aggregate should then be placed in a shallow tray and put in an oven at a temperature of 100 to 110°C. It should be kept at this temperature for 24 ± l/2 hours. Afterward, the aggregate should be removed from the oven, allowed to cool in an airtight container, and then weighed (weight **C**).

7) The specific gravity, apparent specific gravity, and water absorption can be calculated using the following formulas or methods.

$$\text{Specifc Gravity} = \frac{C}{A-B}$$

$$\text{ApparentSpecifc Gravity} = \frac{C}{C-B}$$

$$\text{Water Absorption} = \frac{100(B-C)}{C}$$

$$\text{A} = \text{Weight of saturated aggregate in water} = (\text{A}_1 - \text{A}_2)$$

$$\text{B} = \text{Weight of the saturated surface - dry aggregate in air}$$

$$\text{C} = \text{Weight of ovendried aggregate in air.}$$

$$\text{A}_1 = \text{Weight of aggregate and basket in water}$$

$$\text{A}_2 = \text{Weight of emptybasket in water}$$

Conclusion / Result:

1. The Specific Gravity of a given sample of course aggregate is found to be …….
2. The Water Absorption of a given sample of course aggregate is found to be ……. %

Experiment No. : **03 (b)** **Date**

Title : **Particle Size Distribution of course Aggregates**

Objective: To determine particle size distribution of coarse aggregates by sieving or screening.

Theory:

The process of grading involves determining the distribution of particle sizes in aggregate materials. Grading limits and the maximum aggregate size are specified because they have an impact on various aspects of concrete, such as the amount of aggregate, cement, and water required, workability, pumpability, and durability. Generally, if the water-cement ratio is chosen correctly, a wide range of grading can be used without significantly affecting the strength of the concrete. In cases where gap-graded aggregate is specified, certain particle sizes are intentionally excluded from the size range. Gap-graded aggregates are employed to achieve a consistent texture in exposed aggregate concrete. It is crucial to closely control the proportions of the mix to prevent segregation.

Apparatus:

Test Sieves of 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, Balance, Gauging Trowel, Stopwatch, etc.

Procedure:

1) Before weighing and sieving, the sample must be brought to an air-dry state. This can be achieved by either drying it at room temperature or by heating it between 100|| and 110°C. The air-dry sample should be weighed and then sieved in succession using the appropriate sieves, starting with the largest one. It is important to ensure that the sieves are clean before using them.
2) Each sieve should be shaken individually over a clean tray until only a minimal amount of material passes through, but no less than two minutes in any case. The shaking should involve a varied motion, including backward and forward, left to right, circular clockwise and anti-clockwise movements, and occasional jarring. This ensures that the material moves across the sieve surface in different directions.
3) Hand pressure should not be used to force material through the sieve. If there are any lumps of fine material, they can be gently broken by applying slight pressure with fingers against the side of the sieve.
4) After the sieve process is complete, the material that remains on each sieve, along with any material that has been cleaned from the mesh, should be weighed.

Observation:

Sieve	Weight Retained on Sieve (gms)	Percentage of Weight Retained (%)	Percentage of Weight Passing (%)	Cumulative Percentage of Passing (%)	Remark
80 mm					
40 mm					
20 mm					
10 mm					
4.75 mm					
Total					

Conclusion / Result :

Experiment No. : 04(a) **Date**

Title : **Concrete Mix Design by ACI Committee 211.1 Method**

Objective: To determine the concrete mix proportion by the American Concrete Institute Method of Mix Design (ACI Committee 211.1) Method.
Reference: ACI Committee 211.1

Theory:

Data to be collected:

1. Fineness modulus of selected F.A.
2. Unit weight of dry rodded coarse aggregate.
3. Sp. gravity of coarse and fine aggregates in SSD condition
4. Absorption characteristics of both coarse and fine aggregates.
5. The specific gravity of cement.

Apparatus:

(1) Concrete mixer, (2) Balance, (3) Molds (or forms) for the casting of the test specimens for future testing.

Procedure:

1) From the minimum strength specified, estimate the average design strength either by using the standard deviation or by using the coefficient of variation. The mean strength, $f_m = f_{\min} + ks$

2) Find the water/cement ratio from the strength point of view from **Table 2**. Also, find the water/ cement ratio from a durability point of view from **Table 3** Adopt a lower value out of strength consideration and durability consideration.

Table 2: Relation between water/cement ratio and average compressive strength of concrete, according to ACI 211.1

Average compressive strength at 28 days	*Effective water/cement ratio (by mass)*	
	Non-air entrained concrete	*Air-entrained concrete*
MPa		
45	0.38	–
40	0.43	–
35	0.48	0.40
30	0.55	0.46
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Table 3: Requirements of ACI 318 for W/C ratio and Strength for Special Exposure Conditions.

	Exposure Condition	*Maximum W/C ratio, normal density aggregate concrete*	*Minimum design strength, low density aggregate concrete MPa*
I.	Concrete Intended to be Watertight		
	(a) Exposed to fresh water	0.5	25
	(b) exposed to brackish or sea water	0.45	30
II	Concrete exposed to freezing and thawing in a moist condition:		
	(a) kerbs, gutters, gaurd rails or thin sections	0.45	30
	(b) other elements	0.50	25
	(c) in presense of de-icing chemicals	0.45	30
III.	For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, sea water or spray from these sources	0.40	33

3) Decide the maximum size of aggregate to be used. Generally, for RCC work 20 mm and prestressed concrete 10 mm size are used.

4) Decide workability in terms of slump for the type of job in hand. General guidance can be taken from **Table 4**.

Table 4: Recommended Values of Slump for Various Types of Construction as given by ACI 211.1.

Type of Construction	*Range of Slump mm*
Reinforced foundation walls and footings	20–80
Plain footings, caissons and substructure walls	20–80
Beams and reinforced walls	20–100
Building columns	20–100
Pavements and slabs	20–80
Mass Concrete	20–80

5) The total water in kg/m^3 of concrete is read from **Table 5** entering the table with the selected slump and selected maximum size of aggregate. **Table 5** also gives the approximate amount of accidentally entrapped air in non-air-entrained concrete.

Table 5: Approximate requirements for mixing water and air content for different work abilities and nominal maximum size of Aggregates according to ACI 211.1.

Workability or Air content	*Water Content, Kg/m³ of concrete for indicated maximum aggregate size*							
	10 mm	*12.5 mm*	*20mm*	*25 mm*	40 mm	50 mm	70 mm	150 mm
				Non-air-entrained concrete				
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	200	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	–
Approximate entrapped air content per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
				Air-entrained Concrete				
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	–
Recommended average total air content percent								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

6) Cement content is computed by dividing the total water content by the water/cement ratio.

$$\text{The required cement content} = \frac{\text{Total Water in } kg/m^3}{\text{Water / Cement Ratio from Step 2}}$$

7) From **Table 6** the bulk volume of dry-rodded coarse aggregate per unit volume of concrete is selected, for the particular maximum size of coarse aggregate and fineness modulus of fine aggregate.

Table 6: Dry Bulk Volume of Coarse Aggregate per Unit Volume of Concrete as given by ACI 211.1.

Maximum Size of Aggregate	Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

8) The weight of C.A. per cubic meter of concrete is calculated by multiplying the bulk volume with bulk density.

Therefore, the weight of C.A. in kg/m^3 = Dry Bulk Volume of C.A. Per Unit Volume of Concrete (From Table 6) x Bulk Density of C.A.

9) **Table 7** is the first estimate of the density of fresh concrete for 20 mm maximum size of aggregate and for non-air-entrained concrete.

Table 7: First estimate of density (unit weight) of fresh concrete.

Maximum size of aggregate mm	First estimate of density (unit weight) of fresh concrete	
	Non-air-entrained kg/m^3	Air-entrained kg/m^3
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

10) The solid volume of coarse aggregate in one cubic meter of concrete is calculated by knowing the specific gravity of C.A.

11) Similarly, the solid volume of cement, water, and volume of air is calculated in one cubic meter of concrete.

12) The solid volume of sand is computed by subtracting from the total volume of concrete the solid volume of cement, coarse aggregate, water, and entrapped air.

Item	Ingredients	Weight	Absolute volume	
1	Cement	From Step 6	$\frac{\text{Weight of Cement}}{\text{Sp. gravity of Cement}}\times 10^3 =$	$\times 10^3$
2	Water	From Step 5	$\frac{\text{Weight of Water}}{\text{Sp. gravity of Water}}\times 10^3 =$	$\times 10^3$
3	Coarse Aggregate	From Step 8	$\frac{\text{Weight of C.A.}}{\text{Sp. gravity of C.A.}}\times 10^3 =$	$\times 10^3$
4	Air	---	$\frac{\text{\% of Air Voids}}{100}\times 10^6 =$	$\times 10^3$
	Total absolute volume		=	

13) Wight of fine aggregate is calculated by multiplying the solid volume of fine aggregate by the specific gravity of F.A.

Absolute Volume of F. A. = (1000 – Total absolute volume) x 10^3

Weight of F. A. = Absolute Volume of F. A. x Sp. Gravity of F. A.

Result/ Conclusion:

Final Mix Proportion by American Concrete Institute Method of Mix Design (ACI Committee 211.1) Method

Ingredients	**Cement**	**Fine Aggregate**	**Coarse Aggregate**	**Water**	**Chemical**
Quantity *kg/m³*	300.00	870.95	1423.90	135.00	NM
Ratio	**1.00**	**2.90**	**4.75**	**0.45**	NM

Experiment No.	**:**	**05(a)**	**Date**
Title	**:**	**Making and Curing Concrete Test Specimens in the Laboratory**	

Objective:

This practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration.

Procedure:

Weighing:

1) The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

Procedure for mixing Concrete :

Machine Mixing:

1) Place the coarse aggregate into the mixer. Add a portion of the mixing water and the admixture solution as needed. If necessary, mix the admixture with water before adding it.

2) Start the mixer and gradually add the fine aggregate, cement, and water while the mixer is running. If it's not feasible to add these components while the mixer is running, you can add them to the stopped mixer after it has turned a few revolutions with the coarse aggregate and some of the water.

3) Mix the concrete for 3 minutes once all the ingredients are in the mixer. Afterward, allow the mixture to rest for 3 minutes before conducting a final mixing for 2 minutes.

Hand Mixing:

1) Dry mix the cement and fine aggregate until the mixture is thoroughly blended and has a consistent color.

2) Add the coarse aggregate to the mixture and continue mixing until the coarse aggregate is evenly distributed throughout the batch.

3) Gradually add the water and mix the entire batch until the concrete appears homogeneous and reaches the desired consistency.

4) If multiple mixing cycles are required due to incremental water additions for consistency adjustment, it is recommended to discard the batch and prepare a fresh batch without interrupting the mixing process for trial consistency tests.

Making Specimens:

Place of Molding:

1. Mold specimens as near as practicable to the place where they are to be stored during the first 24 hours.
2. Place molds on a rigid surface free from vibration and other disturbances
3. If it is not practicable to mold the specimens where they will be stored, move them to the place of storage immediately after being struck off.

Placing:

1) Use a scoop, blunted trowel, or shovel to carefully place the concrete into the molds. Ensure that each scoopful, trowelful, or shovelful of concrete is taken from the mixing pan to represent the entire batch.

2) To prevent segregation during the molding process, it may be necessary to remix the concrete in the mixing pan using a shovel.

3) As you discharge the concrete into the molds, move the scoop or trowel around the top edge of the mold. This will help distribute the concrete evenly and minimize the segregation of coarse aggregate within the mold.

4) Before starting the consolidation process, evenly distribute the concrete within the mold by using a tamping rod.

Methods of consolidation :

The preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are: a) Roding, b) Internal vibration, and c) External vibration.

Rodding:

1) Place the concrete into the mold in multiple layers, aiming for approximately equal volumes in each layer. Use the rounded end of the rod to consolidate each layer by applying a specific number of strokes.

2) Consolidate the bottom layer by rodding it throughout its entire depth. For each subsequent layer, distribute the rod strokes evenly across the mold's cross-section. If the layer depth is less than 100mm, penetrate the underlying layer by approximately 12mm with the rod. For layer depths of 100mm or more, penetrate the underlying layer by approximately 25mm.

3) After consolidating each layer with the rod, lightly tap the outside of the mold 10-15 times with the mallet. This tapping action helps to close any holes or voids created during the rodding process.

Vibration:

1) The duration of vibration needed will vary based on the workability of the concrete and the efficiency of the vibrator. Only continue vibrating for as long as necessary to achieve proper consolidation of the concrete.

2) Fill the molds and vibrate the concrete in several layers of approximately equal volume. Add all the concrete for each layer into the mold before beginning the vibration process for that particular layer.
3) Add the final layer, taking care not to overfill the mold by more than 6mm. Afterward, finish the surface as desired.

Finishing:

After consolidation, strike off the surface of the concrete and float or trowel it with a wood or magnesium float.

Curing:

1) The test specimens should be stored in a vibration-free environment with a minimum relative humidity of 90 percent and a temperature of 27° ± 2°C for 24 hours ± ½ hour, starting from the moment water is added to the dry ingredients.
2) After this duration, mark and remove the specimens from the molds. If they are not required for testing within 24 hours, immediately submerge them in clean, fresh water or a saturated lime solution. Keep them submerged until just before the test.
3) The water or solution in which the specimens are submerged should be changed every seven days and maintained at a temperature of 27° ± 2°C. Ensure the specimens are never allowed to dry at any point until they are tested.

Experiment No. : **05(b)** **Date**

Title : **Determination Workability of Fresh Concrete by Slump Cone Test**

Objective: To determine the relative consistency of freshly mixed concrete by the use of the Slump Test.

Theory:

The term "workability" about concrete encompasses a broader and deeper concept compared to the commonly used term "consistency." Consistency refers to the general measure of fluidity or mobility. Workability, on the other hand, considers various factors that contribute to making concrete more easily compactable by reducing internal friction.

These factors are outlined below:

(a) Water Content

(b) Mix Proportions

(c) Size of Aggregates

(d) Shape of Aggregates

(e) Surface Texture of Aggregates

(f) Grading of Aggregates

(g) Use of Admixtures.

Measurement of Workability

Several tests are commonly used to measure the workability of concrete:
(a) Slump Test
(b) Compacting Factor Test
(c) Flow Test
(d) Kelly Ball Test
(e) Vee Bee Consistometer Test

The Slump Test is the most frequently employed method for measuring the consistency of concrete. It can be conducted in the laboratory or on-site. However, it is not suitable for extremely wet or dry concrete. Additionally, the Slump Test does not capture all factors that contribute to workability, nor does it always provide an accurate representation of the concrete's workability.

The Slump Test also provides information about the concrete's characteristics, in addition to the slump value. The pattern of the slump can be observed, as shown in **Figure 7**. A true slump occurs when the concrete slumps evenly. A shear slump, on the other hand, happens when one-half of the cone slides down. In the case of a shear slump, the slump value is determined by measuring the difference in height between the mold height and the average subsidence value.

Apparatus:

The Slump Cone apparatus, used for conducting the slump test, includes the following components:

1) Metallic Mold: The mold is in the shape of a frustum of a cone, with internal dimensions as follows:
   - Bottom diameter: **20 cm**
   - Top diameter: **10 cm**
   - Height: **30 cm**
   - The thickness of the metallic sheet for the mold should be at least 1.6 mm.

2) Weights and Weighing Device: Used to measure the weight of the concrete sample.
3) Tamper: A tool with a diameter of 16 mm and a length of 600 mm. It is used for compacting the concrete during the test.
4) Ruler: Used to measure the slump value of the concrete.
5) Tools and Containers for Mixing: Includes various tools and containers required for mixing concrete, such as a concrete mixer.

Procedure:

1) Moisten the mold and place it on a flat, moist, non-absorbent surface. Ensure it is securely held in place by the operator standing on the two-foot pieces. Immediately fill the mold in three layers, with each layer approximately one-third of the mold's volume.

2) Consolidate each layer by using 25 strokes of the tamping rod. Distribute the strokes uniformly across the cross-section of each layer.

3) When filling and consolidating the top layer, heap the concrete above the mold before starting the consolidation process. If the consolidation causes the concrete to sink below the top edge of the mold, add more concrete to maintain an excess above the mold's top.

4) Once the top layer has been consolidated, level the surface of the concrete by using the screeding and rolling motion of the tamping rod.

5) Carefully and immediately remove the mold from the concrete by lifting it vertically. Lift the mold steadily upward, without any lateral or torsional motion, to a distance of 300 mm in 5 ± 2 seconds.

6) Immediately measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the specimen's top surface. Perform the entire test, from filling to mold removal, without interruption, and complete it within 2½ minutes.

7) If the concrete shows signs of falling away or shearing off from one side or portion of the specimen during the test, disregard the results and perform a new test on another portion of the sample. If two consecutive tests on the same concrete sample exhibit falling away or shearing off, it indicates that the concrete lacks the necessary plasticity and cohesiveness for the slump test to be applicable.

8) After completing the test, the sample can be used for casting future testing specimens.

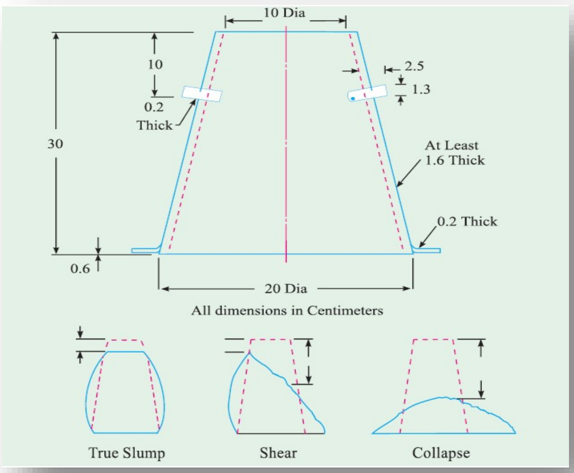


Figure 7: Slump Apparatus.

Observation:

1. The vertical difference between the top of the mold and the displaced original center of the top surface of the specimen ………… mm
2. The pattern of slump is shown as True Slump/Shear Slump/ Collapse Slump.

Conclusion / R :

The slump of concrete ……….. mm indicates **Low/ Medium/ High** Degree of workability.

Experiment No. : 05(c) Date

Title : Determination of Workability of Fresh Concrete by Compacting Factor Test

Objective: To determine the relative consistency of freshly mixed concrete by the use of Compacting Factor Test

Theory:

The Compacting Factor Test is primarily conducted in the laboratory but can also be performed in the field. It offers greater precision and sensitivity compared to the slump test, making it particularly suitable for concrete mixes with very low workability, which is typically used when compacting concrete through vibration. This method applies to plain and air-entrained concrete, using lightweight, normal-weight, or heavy aggregates with a nominal maximum size of 40 mm or less. However, it does not apply to aerated concrete or no-fine concrete.

Apparatus:

To conduct the Compacting Factor Test, the following equipment is required:

- Compacting Factor Apparatus
- Trowel
- Scoop, approximately 150 mm long
- Balance capable of weighing up to 25 kg with a sensitivity of 10 g
- Weight and weighing device.
- Tamper, with a diameter of 16 mm and a length of 600 mm
- Ruler
- Tools
- Containers for mixing, such as a concrete mixer, etc.

Procedure:

1) Ensure that the internal surfaces of the hoppers and cylinder are thoroughly clean and free from excess moisture or any concrete residue before commencing the test.
2) Gently place the sample of concrete to be tested into the upper hopper using a scoop. Open the trap door immediately after filling or approximately 6 minutes after adding water, allowing the concrete to fall into the lower hopper. Keep the cylinder covered during this process.
3) Once the concrete has come to rest, uncover the cylinder, and open the trap door of the lower hopper, allowing the concrete to flow into the cylinder.

4) Some concrete mixes may stick in one or both hoppers. If this occurs, gently push the tamping rod into the concrete from the top to assist its movement.

5) Cut off the excess concrete remaining above the top level of the cylinder. Hold a trowel in each hand with the blades parallel to the ground, and simultaneously move them from opposite sides across the top of the cylinder while pressing them against the cylinder's top edge. Wipe the outside of the cylinder clean. Perform this entire process in a location free from vibration or shock.

6) Determine the weight of the concrete to the nearest 10 g. This weight is known as the "weight of partially compacted concrete" (Wp).

7) Refill the cylinder with concrete from the same sample in layers of approximately 50 mm depth. Compact each layer thoroughly using a compacting rod or vibration until full compaction is achieved. Carefully strike off and level the top surface of the fully compacted concrete with the top of the cylinder. Clean the outside of the cylinder.

8) Determine the weight of the fully compacted concrete to the nearest 10 g. This weight is known as the "weight of fully compacted concrete" (Wf).

9) The compacting factor (Fc) can be calculated using the following formula:

$$\text{The compacting factor} = \frac{\text{"weight of partially compacted concrete"}, W_p.}{\text{"weight of fully compacted concrete"}, W_f.}$$

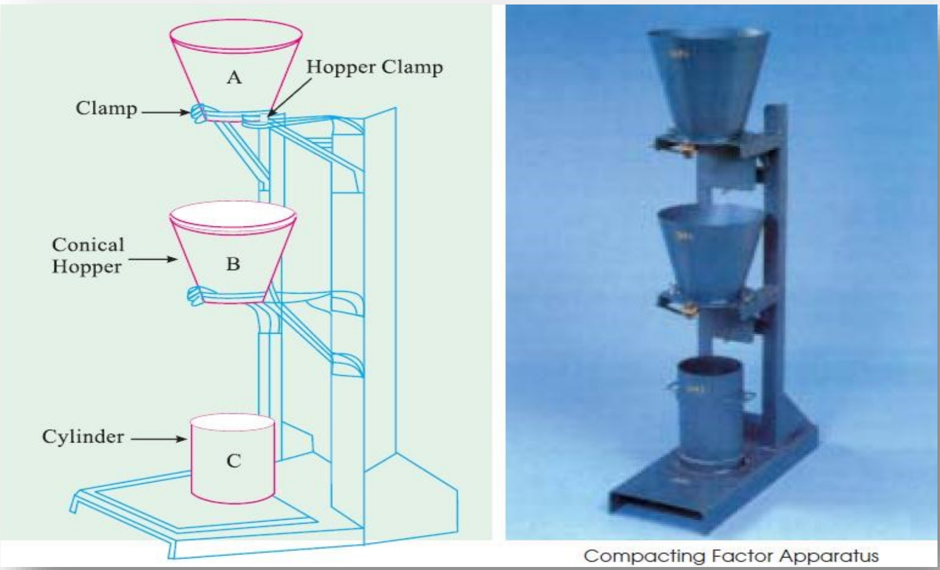


Figure 8: Compacting Factor Apparatus.

Observation:

The compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It shall normally be stated to the nearest second decimal place.

No	Description	Sample 1	Sample 2	Sample 3
1.	Weight of Empty Cylinder (W1)			
2.	Weight of Cylinder + Free Fall Concrete (W2)			
3.	Weight of Cylinder + Hand Compacted Concrete (W2)			
4.	Weight of Partially Compacted Concrete (W_p=W2-W1)			
5.	Weight of Fully Compacted Concrete (W_f=W2-W1)			
6	The Compacting Factor =W_p/W_f			

Experiment No. : **05(d)** **Date**

Title : **Determine the Compressive Strength of Cubic Concrete Specimens**

Objective: The test method covers the determination of the compressive strength of cubic concrete specimens. It consists of applying a compressive axial load to molded cubes at a rate that is within a prescribed range until failure occurs.

Theory:

- **Age at Test -** Tests shall be made at the recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ±½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.
- **Number of Specimens -** At least three specimens, preferably from different batches, shall be made for testing at each selected age.

Apparatus:

- **Testing Machine -** The testing machine may be of any reliable type, of sufficient capacity for the tests, and capable of applying the load at the rate. The permissible error shall be not greater than ± 2 percent of the maximum load.
- **Cube Moulds -** The mold shall be of 150 mm
- **Cylinders -**The cylindrical mold shall be 150 mm in diameter and 300 mm in height
- Weights and weighing devices, Tools, and containers for mixing, tampering (square in cross-section), etc.

Procedure:

1) Sampling of Materials - Aggregate samples for each concrete batch should have the desired grading and be air-dried. Cement samples should be thoroughly mixed upon arrival at the laboratory, either by hand or in a suitable mixer, ensuring proper blending and uniformity.

2) Proportioning - The proportions of materials, including water, in concrete mixes used for testing material suitability should be similar to those to be used in the actual project.

3) Weighing - Cement, aggregates of each size, and water quantities for each batch should be determined by weight with an accuracy of 0.1 percent of the total batch weight.

4) Mixing Concrete - Concrete should be mixed by hand or preferably in a laboratory batch mixer to prevent loss of water or materials. Each batch should have approximately 10 percent excess after molding the desired number of test specimens.

5) Mold - Test specimens should be cubical with dimensions of 15 × 15 × 15 cm. Alternatively if the largest aggregate size is not larger than 2 cm, 10 cm cubes can be used. Cylindrical specimens should have a length equal to twice the diameter.

6) Compacting - Test specimens should be made as soon as possible after mixing, ensuring full compaction without segregation or excessive laitance.

7) Curing - Test specimens should be stored in a vibration-free environment with moist air at a minimum relative humidity of 90 percent and a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time water is added.

8) Placing the Specimen in the Testing Machine - The testing machine's bearing surfaces should be cleaned, and any loose sand or debris should be removed from the specimen's surfaces that will be in contact with the compression platens.

9) For cubes, place the specimen in the machine so that the load is applied to the opposite sides of the original cube, not the top and bottom.

10) Align the specimen's axis carefully with the center of thrust of the spherically seated platen. No packing should be used between the specimen faces and the steel plate of the testing machine.

11) Apply the load smoothly and continuously at a rate of approximately 140 kg/sq cm/min until the specimen's resistance to the increasing load breaks down and can no longer sustain a greater load.

12) Record the maximum load applied to the specimen and note the appearance of the concrete and any unusual features in the type of failure.

Figure 9: Testing Machine.

Observation:

Data for the calculation of the mix proportion

No.	Description	Value
1	Compressive strength at 28 days	
2	Slump	
3	Type of cement	
4	The specific gravity of cement	
5	Type of sand	
6	The specific gravity of sand	
7	Fineness modulus	
8	Type of coarse aggregate	

Calculations of Mix Proportion

Mix proportion of concrete	For 1 cubic meter of concrete	For one batch of mixing
Coarse aggregate (kg)		
Fine aggregate (kg)		
Cement (kg)		
Water (kg)		
S/A		
w/c		
Admixture		

No.	Age of Cube	Weight of Cement Cube (gms)	Cross-Sectional area (mm^2)	Load (N)	Compressive strength (N/mm^2)	Average Compressive strength (MPa)
1	7 Days					
2						
3						
4	28 Days					
5			`			
6						

Conclusion / R :

The average 7-day compressive Strength of a concrete sample is found

to be ....

The average 28-day compressive Strength of a concrete sample is found

to be ....

Experiment No. : **05(e)** **Date**

Title : **Determine the Flexural Strength of Cubic Concrete Specimens**

Objective: This clause deals with the procedure for determining the flexural strength of molded concrete flexure test specimens.

Theory:

- **Age of Testing** - The tests should be conducted at standard ages for the test specimens, typically 7 and 28 days. In cases where early strength measurements are required, tests can be carried out at 24 hours ± ½ hour and 72 hours ± 2 hours. The ages of the specimens should be calculated from the moment water is added to the dry ingredients**.**
- **Number of Specimens** - For each selected age, a minimum of three specimens, preferably from different batches, should be prepared for testing.

Apparatus:

- **Testing Machine** - The testing machine should be a reliable type with sufficient capacity for the tests and capable of applying the load at the specified rate. The allowable error should not exceed ± 2 percent of the maximum load.
- **Beam Molds** - The standard size for beam molds should be 15 × 15 × 70 cm. Alternatively, if the largest nominal size of the aggregate is not larger than 19 mm, specimens measuring 10 × 10 × 50 cm can be used.
- Weights and Weighing Devices, Tools, and Containers - Adequate weights and weighing devices, as well as tools and containers for mixing and tampering (square in cross-section), should be used.

Procedure:

1) **Sampling of Materials** - Aggregate samples for each concrete batch should have the desired grading and be air-dried. Upon arrival at the laboratory, cement samples should be thoroughly mixed, either by hand or in a suitable mixer, to ensure optimal blending and uniformity.
2) **Proportioning** - The proportions of materials, including water, in concrete mixes used for assessing material suitability should closely resemble those to be used in the actual construction work.
3) **Weighing** - The quantities of cement, each size of aggregate, and water for each batch should be determined by weight, with an accuracy of 0.1 percent of the total batch weight.
4) **Mixing Concrete** - Concrete should be mixed by hand or, preferably, in a laboratory batch mixer, ensuring minimal loss of water or other materials. Each batch should be of sufficient size to provide about 10 percent excess after molding the desired number of test specimens.

5) **Mold** - The standard size for specimens should be 15 × 15 × 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens measuring 10 × 10 × 50 cm may be used.

6) **Compacting** - Test specimens should be made as soon as possible after mixing, ensuring full compaction of the concrete without segregation or excessive laitance.

7) **Curing** - Test specimens should be stored in a vibration-free location with moist air at a minimum relative humidity of 90 percent and a temperature of 27° ± 2°C for 24 hours ± ½ hour from the moment water is added to the dry ingredients.

8) **Placing the Specimen in the Testing Machine** - The surfaces of the supporting and loading rollers should be cleaned, and any loose sand or debris should be removed from the specimen's surfaces that will come into contact with the rollers.

9) The specimen should be placed in the machine so that the load is applied to the uppermost surface as it was cast in the mold, along two lines spaced 20.0 or 13.3 cm apart.

10) Carefully align the axis of the specimen with the axis of the loading device. No packing should be used between the bearing surfaces of the specimen and the rollers.

11) Apply the load smoothly and continuously, ensuring that the extreme fiber stress increases at an approximate rate of 7 kg/sq cm/min. This corresponds to a loading rate of 400 kg/min for 15.0 cm specimens and 180 kg/min for 10.0 cm specimens.

12) Increase the load until the specimen fails, and record the maximum load applied during the test. Note the appearance of the fractured faces of the concrete and any unusual features in the type of failure.

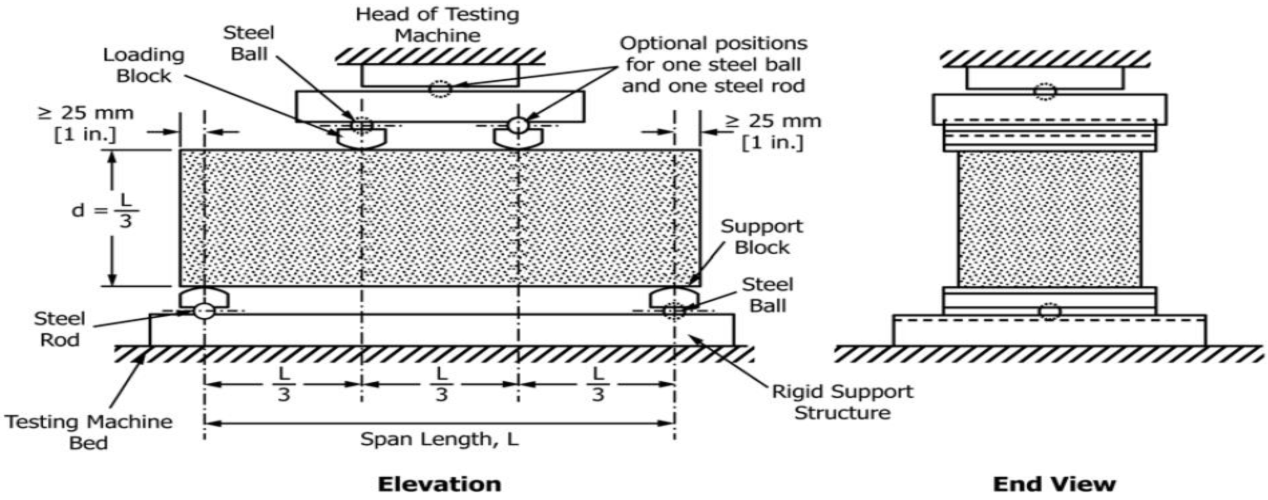


Figure 10: Arrangement for Loading of Flexural Test Specimen.

Observation:

Calculations of Mix Proportion

Mix proportion of concrete	For 1 cubic meter of concrete	For one batch of mixing
Coarse aggregate (kg)		
Fine aggregate (kg)		
Cement (kg)		
Water (kg)		
S/A		
w/c		
Admixture		

No.	Age of Specimen	Identification Mark	Size of Specimen (mm)	Span Length (mm)	Maximum Load (N)	Position of Fracture ‗a‘ (mm)	Modulus of Rupture (MPa)
1							
2	7 Days						
3							
4							
5	28 Days		`				
6							

Calculation:

The flexural strength of the specimen shall be expressed as the modulus of rupture f_b, which, if ‗a' equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq cm as follows:

$$f_b = \frac{P \times l}{a \times d^2}$$

when a is greater than 20.0 cm for a 15.0 cm specimen or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3P \times a}{b \times d^2}$$

when a is less than 20.0 cm but greater than 17.0 cm for a 15.0 cm specimen, or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen

where

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen at the point of failure,

l = length in cm of the span on which the specimen was supported, and

p = maximum load in kg applied to the specimen.

Conclusion / R :

The average 7-day modulus of the Rupture of the concrete sample is

found to be....

The average 28-day modulus of the Rupture of the concrete sample is

found to be...

Experiment No. : **05(f)** **Date**

Title : **Determine Splitting Tensile Strength of Cylindrical Concrete Specimens**

Objective: This method covers the determination of the splitting tensile strength of cylindrical concrete specimens.

Theory:

- **Age of Testing -** The tests should be conducted at standard ages for the test specimens, typically 7 and 28 days. In cases where early strength measurements are required, tests can be carried out at 24 hours ± ½ hour and 72 hours ± 2 hours. The ages of the specimens should be calculated from the moment water is added to the dry ingredients.
- **Number of Specimens -** For each selected age, a minimum of three specimens, preferably from different batches, should be prepared for testing.

Apparatus :

- **Testing Machine -** The testing machine should be reliable, have sufficient capacity for the tests, and be capable of applying the load at the rate specified in section 5.5. The allowable error should not exceed ± 2 percent of the maximum load.
- **Cylinders -** The cylindrical mold used should have a diameter of 150 mm and a height of 300 mm. Weights, Weighing Devices, Tools, and Containers - Adequate weights and weighing devices, as well as tools and containers for mixing and tampering (square in cross-section), should be used.

Procedure:

1) Sampling of Materials - Aggregate samples for each concrete batch should have the desired grading and be air-dried. Upon arrival at the laboratory, cement samples should be thoroughly mixed dry either by hand or in a suitable mixer to ensure optimal blending and uniformity.

2) Proportioning - The proportions of materials, including water, in concrete mixes used to assess material suitability should closely resemble those to be used in the actual construction work.

3) Weighing - The quantities of cement, each size of aggregate, and water for each batch should be determined by weight, with an accuracy of 0.1 percent of the total batch weight.

4) Mixing Concrete - Concrete should be mixed by hand or preferably in a laboratory batch mixer, ensuring minimal loss of water or other materials. Each batch of concrete should be of sufficient size to provide about 10 percent excess after molding the desired number of test specimens.

5) Mold - The cylindrical mold used should have a diameter of 150 mm and a height of 300 mm, conforming to the specifications of IS: 10086-1982.

6) Compacting - Test specimens should be made as soon as possible after mixing, ensuring full compaction of the concrete without segregation or excessive laitance.

7) Curing - Test specimens should be stored in a vibration-free location with moist air at a minimum relative humidity of 90 percent and a temperature of 27° ± 2°C for 24 hours ± ½ hour from the moment water is added to the dry ingredients.

8) Placing the Specimen in the Testing Machine - The bearing surfaces of the supporting and loading rollers should be cleaned, and any loose sand or debris should be removed from the surfaces of the specimen that will come into contact with the rollers.

9) Two bearing strips made of nominal 1/8 inch (3.175 mm) thick plywood, free of imperfections, approximately 25 mm wide, and of length equal to or slightly longer than that of the specimen should be provided for each specimen.

10) The bearing strips should be placed between the specimen and both the upper and lower bearing blocks of the testing machine or between the specimen and the supplemental bars or plates.

11) Draw diametric lines at each end of the specimen using a suitable device to ensure they are in the same axial plane. Center one of the plywood strips along the center of the lower bearing block.

12) Place the specimen on the plywood strip and align it so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip.

13) Place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder. Apply the load continuously and without shock at a constant rate within the range of 689 to 1380 kPa/min splitting tensile stress until the specimen fails.

14) Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and the appearance of the fracture.

Figure 11: The jig for aligning concrete cylinder and bearing strips

Figure 12: Fitting the cylinder in the compression machine.

Observation:

Calculations of Mix Proportion

Mix proportion of concrete	For 1 cubic meter of concrete	For one batch of mixing
Coarse aggregate (kg)		
Fine aggregate (kg)		
Cement (kg)		
Water (kg)		
S/A		
w/c		
Admixture		

No.	Age of Specimen	Identification Mark	Dia of Specimen (mm)	Depth (mm)	Maximum Load (N)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
1	7 Days						
2							
3							
4	28 Days						
5							
6							

Calculation:

Calculate the splitting tensile strength of the specimen as follows:

$$T = \frac{2P}{\pi L d}$$

where

T: splitting tensile strength, kPa

P: maximum applied load indicated by testing machine, kN

L: Length, m

d: diameter

Conclusion / R :

The average 7-day tensile Strength of a concrete sample is found to be ….

The average 28-day tensile Strength of a concrete sample is found to be …

Experiments described as per Al-Baha University Curriculum for Strength of Material laboratory.

1- Introduction

The tests most commonly used in evaluating the quality of metal products include the tension, hardness, notched-bar impact, creep, and fatigue tests. Other types of tests (e.g. bend, cupping, KIc, etc.) may be used depending on the particular product or its intended application.
One of the primary purposes, in making mechanical property tests of metal products, is to determine conformance or non-conformance with specifications. The data may thus serve as an index to the quality of a product in comparison with similar products obtained previously. Since variations in the methods used in preparing test specimens may have a significant effect on the test data, it is essential that careful and uniform procedures be followed in machining.

2-Laboratory 1: Tensile Test

2-1 Introduction:

Tensile testing is one of the most fundamental tests for engineering, and provides valuable information about a material and its associated properties. These properties can be used for design and analysis of engineering structures, and for developing new materials that better suit a specified use.
In a tensile test, a sample is machined to specific dimensions and mounted within a universal testing machine. The machine applies an increasing tensile load to the sample, while measuring the extension in the length of the sample and the instantaneous load. The tension is increased until the sample fractures; along the way, materials can undergo strain hardening, necking, and other effects. The raw output of the tensile test is in the form of a load vs. crosshead extension curve, although modern machines also include the ability to directly measure the extension of the sample. Calculations are used to normalize out the effect of sample dimension to produce a stress-strain curve, which should ideally be a property of the material. (Fig. 2.1)

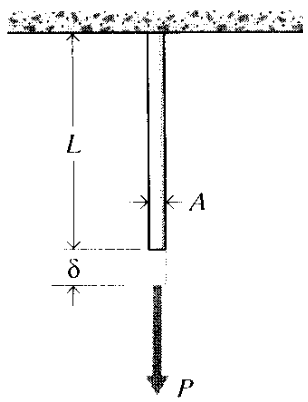


Figure 2.1: The tension test

2-2Tensile stress (σ_t)

If σ>0 the stress is tensile. i.e. The fibers of the component tend to elongate due to the external force. A member subjected to an external force tensile P and tensile stress distribution due to the force is shown in the given figure. 2.2

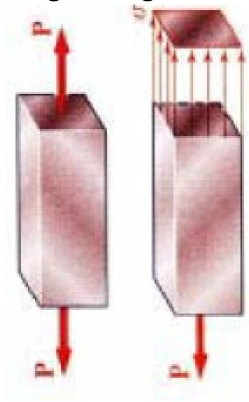


Figure. 2.2

2-3 Objective:

1- Students are required to understand the principle of a uniaxial tensile testing and gain their practices on operating the tensile testing machine to achieve the required tensile properties.
2- Students are able to explain load-extension and stress-strain relationships and represent them in graphical forms (stress - strain curve) (load - deflection curve).
3- To evaluate the values of ultimate tensile strength, yield strength, % elongation, fracture strain and Young's Modulus E of the selected metals when subjected to uniaxial tensile loading.
4- Students can explain deformation and fracture characteristics of different materials such as aluminum, steels or brass when subjected to uniaxial tensile loading.

2-4The machine used to test tensile:

WP 300 Universal testing machine (figure 2.3)

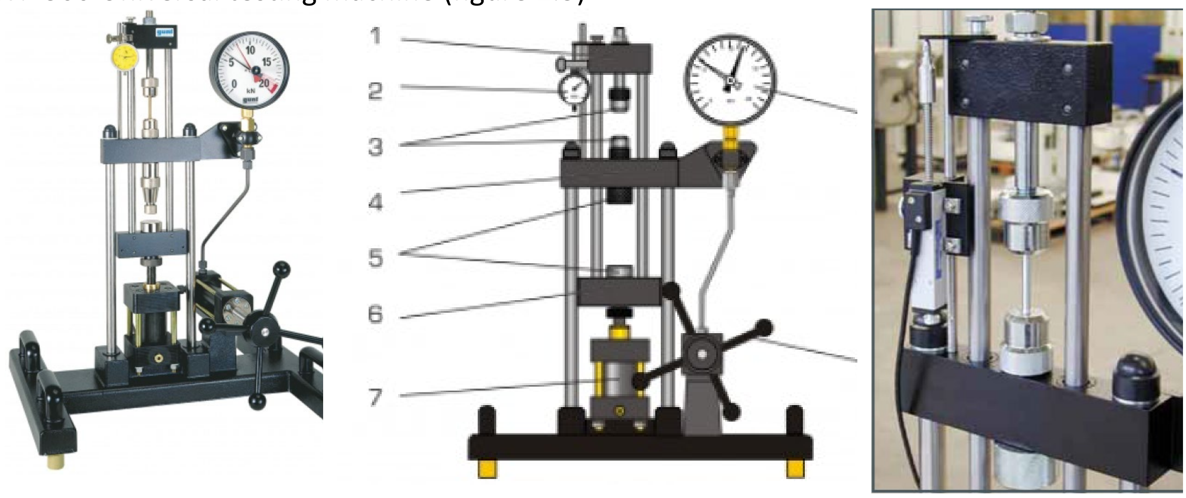


Figure 2.3 WP 300 Universal testing machine

(1 upper cross-member, 2 dial gauge for elongation, 3 clamp for tensile specimens,4 crosshead, 5 compression piece and pressure plate, 6 lower cross-member, 7 hydraulic cylinder, 8 hand wheel, 9 force gauge)

2-5Test specimens:

One type of specimen commonly used in Universal testing machine is shown in figure 2.4but there are three material steel-brass- aluminum

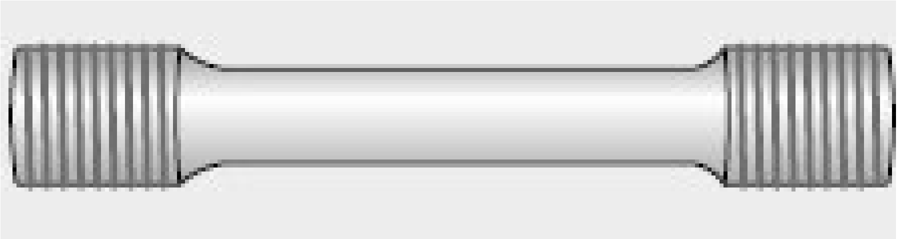


figure 2.4

2-6 Procedure:

The students will observe the testing of the various samples as the mechanical testing machine is operated by Lecturer.

1) Measure the specimen dimensions.(D=6mm , L=60mm).
2) The specimen is attached the grips of the testing machine (Figure 2.1).
3) A dial gauge used to measure elongation, while the specimen is pulled in tension, every 0.5 KN (the load is increased gradually) the readings elongation δ data should be Recording the direct results from the test in table 2.1.
4) The specimen is pulled to failure. Figure 2.5
5) Calculate the deflection δ stress σ , strain ξ , and Modulus of Elasticity E
6) Plot the diagram stress-strain(σ-ξ) and load-deflection(P-δ)

Table 2.1.

Number	Load P, kN	Dial reading mm	Deflection δ, mm	Stress,N/mm^2 $\sigma = \frac{P}{A}$	Strain $\varepsilon = \frac{\delta}{L_0}$	Modulus of Elasticity $E = \frac{\sigma}{\xi}$ N/mm^2
1	0					
2	0.5					
3	1					
4	1.5					
5	2					
6	2.5					
7	3					
8	3.5					
9	4					
10	4.5					
11	5					
12	5.5					
13	6					

(A= $\frac{\pi D^2}{4}$ ……………………………………, $E = \frac{\sum Ei}{i}$ ……………………)

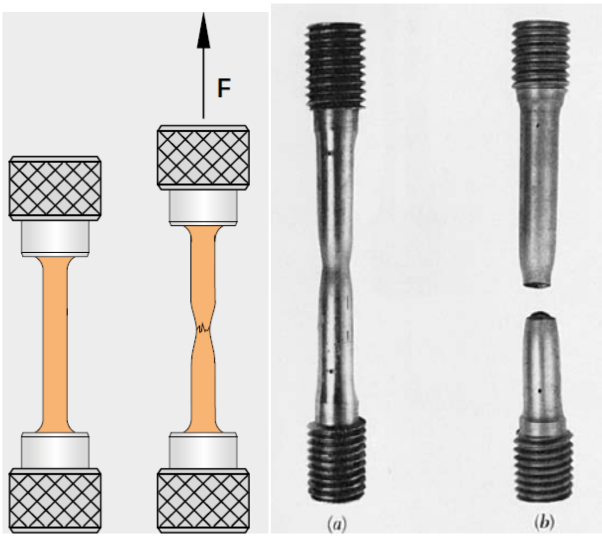


Figure 2.6 Tested specimen of a ductile

Figure 2.7Load gauge

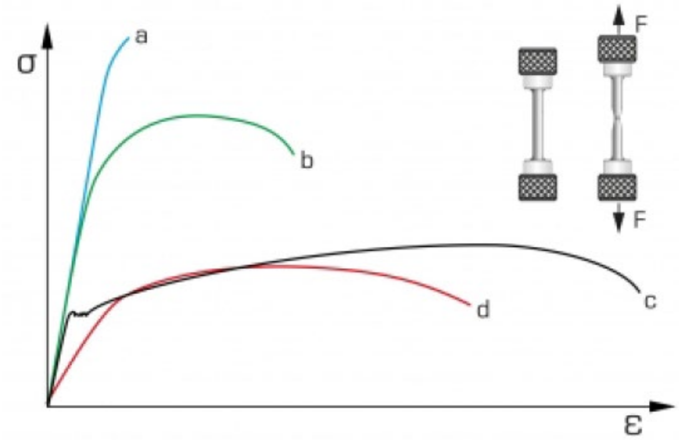


Figure 2.8 Stress-strain diagram for various materials: a- hardened steel,
b- tempered steel, c- annealed steel, d - alloyed aluminum

Figure 2.9 dial guage material.

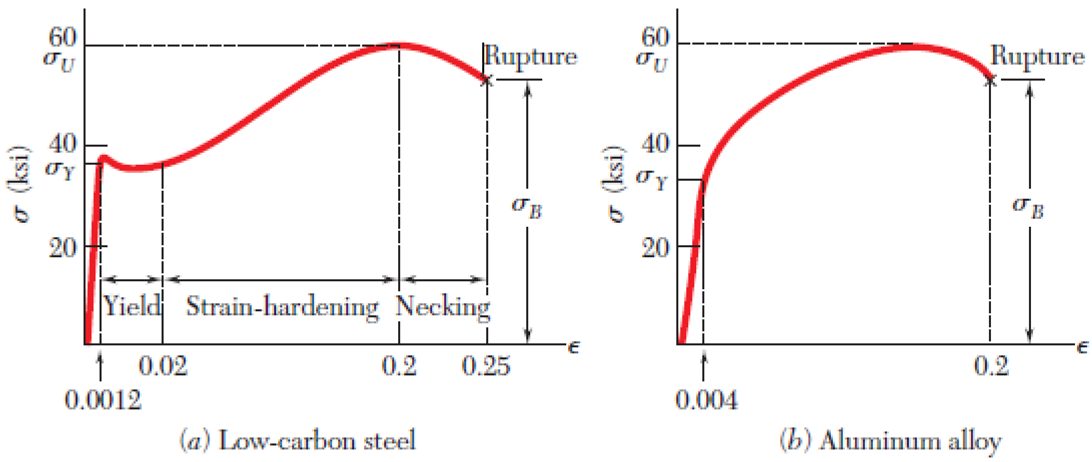
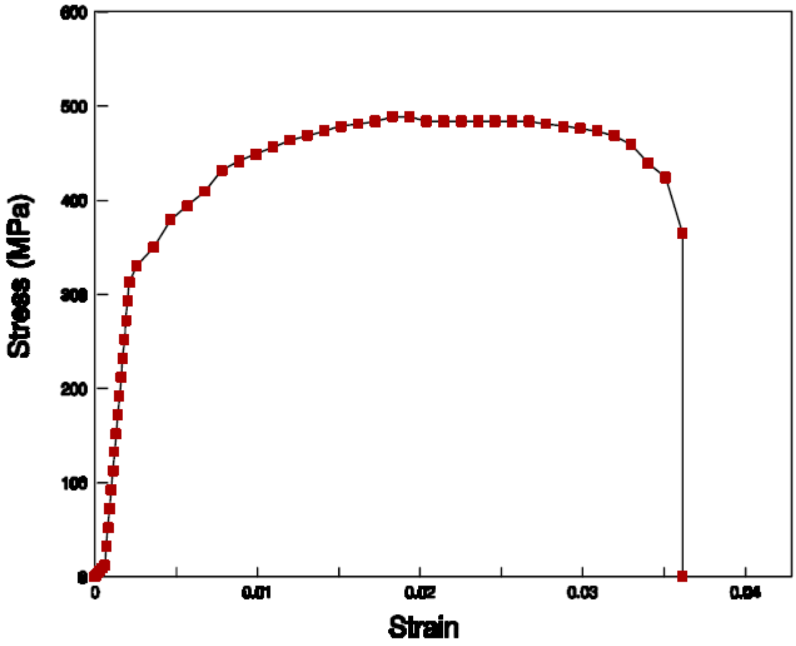
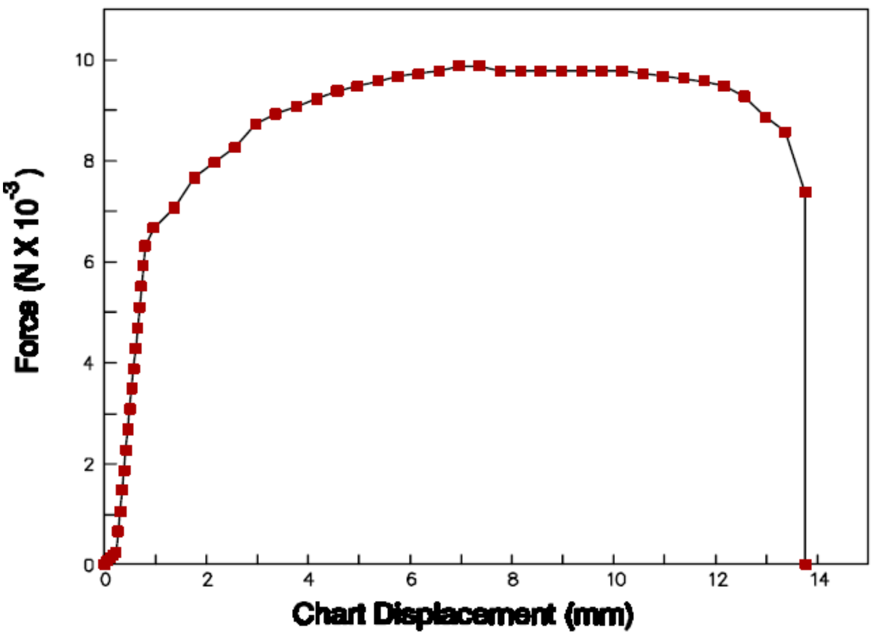


Figure 2.10Stress-strain diagrams of two typical ductile materials

STRESS-STRAIN CURVE



LOAD-DEFLECTION CURVE



STRESS-STRAIN CURVE

3-Laboratory 2: Compressive strength tests

3-1 Introduction:

In a compression test, a sample is machined to specific dimensions and mounted within a universal testing machine. The machine applies an increasing load to the sample, while measuring the deflection in the length of the sample and the instantaneous load. The load is increased until the sample fractures;. The raw output of the Compressive test is in the form of a load vs. crosshead deflection curve, although modern machines also include the ability to directly measure the deflection of the sample. Calculations are used to normalize out the effect of sample dimension to produce a stress-strain curve, which should ideally be a property of the material.

3-2 Objective:

1- Students are required to understand the principle of a uniaxial compressive testing and gain their practices on operating the compressive testing machine to achieve the required compressive properties.
2- Students are able to explain load- deflection and stress-strain relationships and represent them in graphical forms (stress - strain curve) (load - deflection curve).
3- To evaluate the values of ultimate compressive strength, yield strength, %deflection, fracture strain and Young's Modulus E of the selected metals when subjected to uniaxial compressive loading.
4- Students can explain deformation and fracture characteristics of different materials such as wood when subjected to uniaxial compressive loading.

3-3 The machine used to compressive test:

WP 300 Universal testing machine (figure 3.1)

Figure 3.1 WP 300 Universal testing machine

3-4Test specimens:

A Cube of wood (….mmx….mmx…..mm) figure 3.2

figure 3.2

3-5Procedure:

The students will observe the testing of the woods samples as the mechanical testing machine is operated by Lecturer.

1) Measure the specimen dimensions.
2) Place the specimen in designated space (special place) in machine (Figure 3.1).
3) A dial gauge used to measure shortening, while the specimen is exposed in to compressive, every 0.5 KN (the load is increased gradually) the readings deflection δ data should be Recording the direct results from the test in table 3.1.
4) The specimen is compressed to failure. Figure 3.3

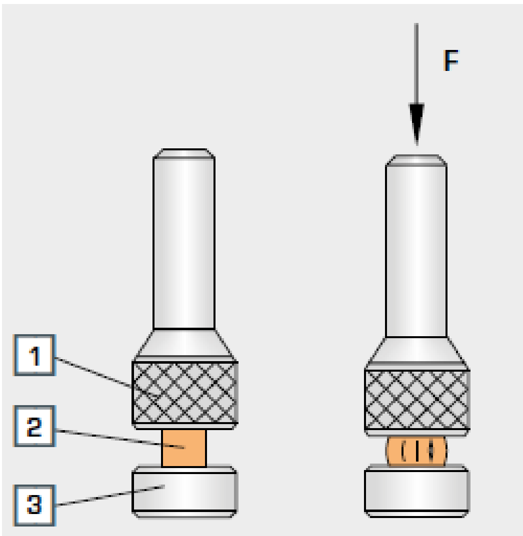


Figure 3.3

5) Calculate the deflection δ ,stress σ , strain ξ , and Modulus of Elasticity E
6) Plot the diagram stress-strain(σ-ξ) and load-deflection(P-δ)

Table 2.1.

Number	Load P, kN	Dial reading mm	Deflection δ, mm	Stress, N/mm^2 $\sigma = \frac{P}{A}$	Strain $\varepsilon = \frac{\delta}{L_0}$	Modulus of Elasticity $E = \frac{\sigma}{\xi}$ N/mm^2
1	0					
2	0.5					
3	1					
4	1.5					
5	2					
6	2.5					
7	3					
8	3.5					
9	4					
10	4.5					
11	5					
12	5.5					
13	6					

A= $w * l$..

$E = \frac{\sum E_i}{i}$ ....

4-Laboratory 3: Torsion tests

4-1 Introduction:

The torsion test is a destructive testing method that studies the plastic behaviour of materials. In practice, components that are twisted in their application (e.g. screws, shafts, axles, wires and springs) are studied with this test method.
Components that are subjected to rotary movements are twisted. This twisting is referred to as torsion. The torsional stiffness determined in the torsion test serves as orientation for the load capacity of the material.
In the torsion test, a specimen is clamped at one end and subjected to the load of a steadily increasing moment, known as the twisting moment or torsional moment. The twisting moment causes shear stresses in the cross section of the specimen and a stress state that leads to deformation and ultimately to **fracture** figure 4.1.

Figure 4.1: Test process in the torsion test ,1 rigid clamping, 2 specimen, 3 rotating clamping, 4 drive;M_t twisting moment, **γ** shearing angle, **ϕ** twisting angle, **τ** shear stress

4-2 Objective:

Torsion tests with different materials and load until specimen fracture

1- Determine the twisting strength- torsion stress
2- Determine Modulus of Rigidity G of the selected metals
3- Plot the diagram of twisting moment over twisting angle

4-3The machine used to torsion test:

WP 500 Torsion test, 30Nm (figure 4.2)

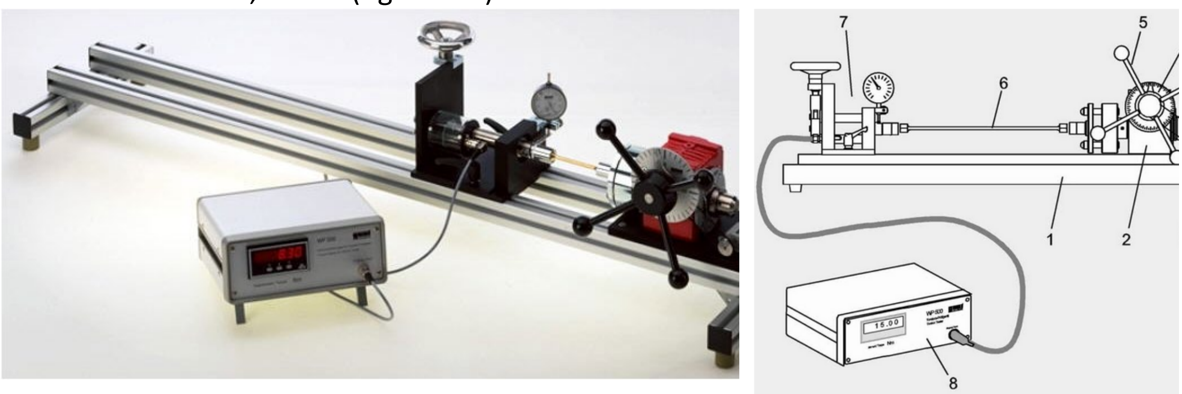


Figure 4.2 WP 500 **Torsion test, 30Nm**
1 base frame, 2 worm gear, 3 revolution counter, 4 protractor, 5 hand wheel for test torque, 6 test bar, 7 measuring device, can be slid along the frame, with strain gauge measuring shaft and compensation unit, 8 measuring amplifier with display

4-4Test specimens:

Torsion specimens for torsion tests each three specimens made of: steel, aluminum, brass for WP 500 Torsion test, 30Nm is shown in figure 4.3

Technical data

- Length: 115mm
- clamping length: 75mm

• Specimen diameter in measured cross section: 6mm

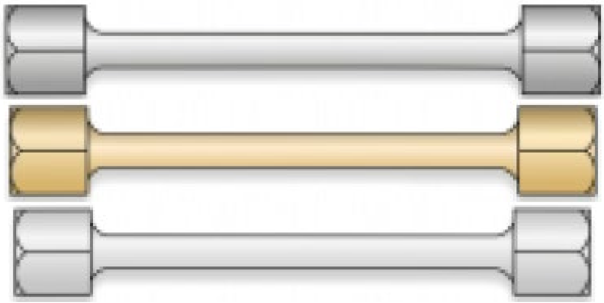


figure 4.3 , steel-brass- aluminum

4-5Procedure:

1) The specimen is attached the grips of the testing machine (Figure 4.2).
2) The twisting moment is applied manually by means of a handwheel and a worm gear (the load is increased gradually). A Angle disk used to measure angle, (the load is increased gradually) the readings angle data should be Recording the direct results from the test (transmission ratio: 1:63) with twisting moment in table 3.1.The specimen is pulled to failure.
3) Calculate the torsion stress τ , using the formula

$$\tau = \frac{Tc}{J} \quad , \text{N/mm}^2$$

4) Calculate the Modulus of Rigidity G, using the formula

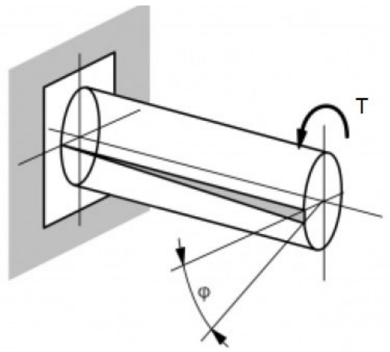
$$G = \frac{TL}{J\theta\left(\frac{\pi}{180}\right),} \qquad \text{N/mm}^2$$

5) Plot the diagram of twisting moment over twisting angle

Table 3.1

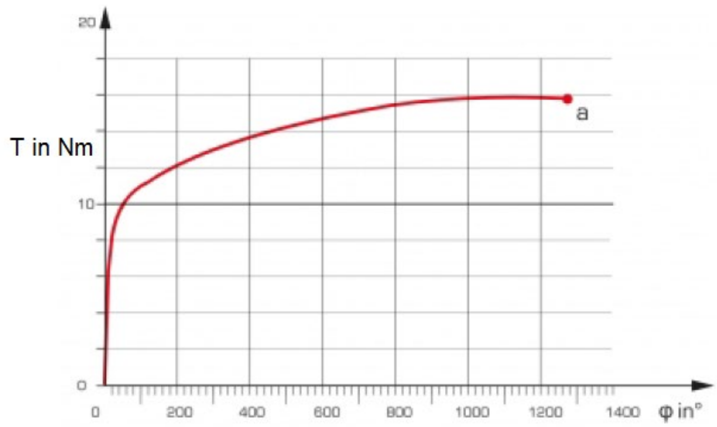
Number of revolutions	Angle of twist (θ)	Torque(T) Nmm	Torsion Stress, τ , N/mm^2	Modulus of Rigidity $G = \frac{TL}{J\theta\left(\frac{\pi}{180}\right),}$ N/mm^2
0				
0.25				
0.50				
0.75				
1				
1.5				
2				
2.5				
3				
4				
5				
6				
7				
8				

($J=\frac{\pi c^4}{2}$ ...., $G = \frac{\sum G_i}{i}$ ....)



Principle of operation of torsion test: T twisting moment, ϕ twisting angle

The diagram of twisting moment T over twisting angle ϕ.



Torsion test of metallic materials to fracture:
T twisting moment, ϕ twisting angle, a specimen fracture

5-Laboratory 4: Impact Testing

5-1 Introduction:

Charpy notched-bar impact test classic method from destructive materials testing for quality control and analysis of the fracture behavior of metallic materials

5-2 Impact test to determine the toughness property

The impact test is a method with sudden loading and is suitable primarily for determining the cleavage fracture tendency or toughness property of a material. This test method does not provide any values of material characteristics. The determined values of the impact test, the notched-bar impact strength, do not fit directly into calculations on strength. Rather, they help only with a rough selection of materials for a specific task. The deformation behavior is often an important criterion for the selection of materials. It can be used to identify quickly which of the selected materials are brittle or tough. The brittleness of the material does not depend on the material alone, but also on other external conditions such as temperature or stress state. Different testing methods are used to determine the notched bar impact strength. In the Charpy test, the test body is mounted on two sides and a pendulum strikes the Centre of the test body at the height of the notch. In the Izod and Dynstat tests, the test body is upright and a pendulum strikes the free end of the test body above the notch.

5-3 Principle of the Charpy notched-bar impact test

In the notched-bar impact test, a pendulum hammer falls down from a maximum height. At its lowest point, the hammer strikes the rear of a notched specimen according to Charpy's principle. If the abutment penetrates or passes through the specimen, the hammer dissipates its impact energy to the specimen. The residual energy of the hammer is reduced when swinging through the lowest possible point (zero point) and the hammer decelerates. When the hammer swings through the zero point, the trailing pointer is dragged along and the applied work for the notched-bar impact is displayed on a scale. The shape of the notched-bar specimen is standardized.
The necessary notched-bar impact work is the force needed to penetrate a defined notched specimen. The notched-bar impact strength determined from the notched-bar impact work.

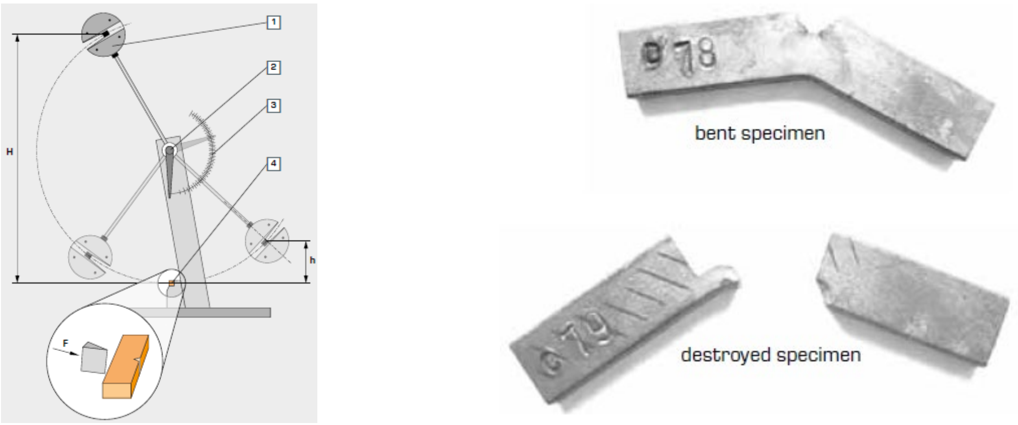


Figure 5-1 1 pendulum hammer, 2 axis of rotation, 3 scale with trailing pointer, 4 notched specimen; H height of fall, h height of rise, F force

5-4 Objective:

1- Determine the notched-bar impact work

2- Determine the notched-bar **impact strength**

3- Analyze the fracture surface **characteristics of metallic materials**

4- Plot a notched-bar impact work–temperature diagram

5-5The machine used to test tensile:

WP 400-Impact test, 25Nm (Figure 5.2)

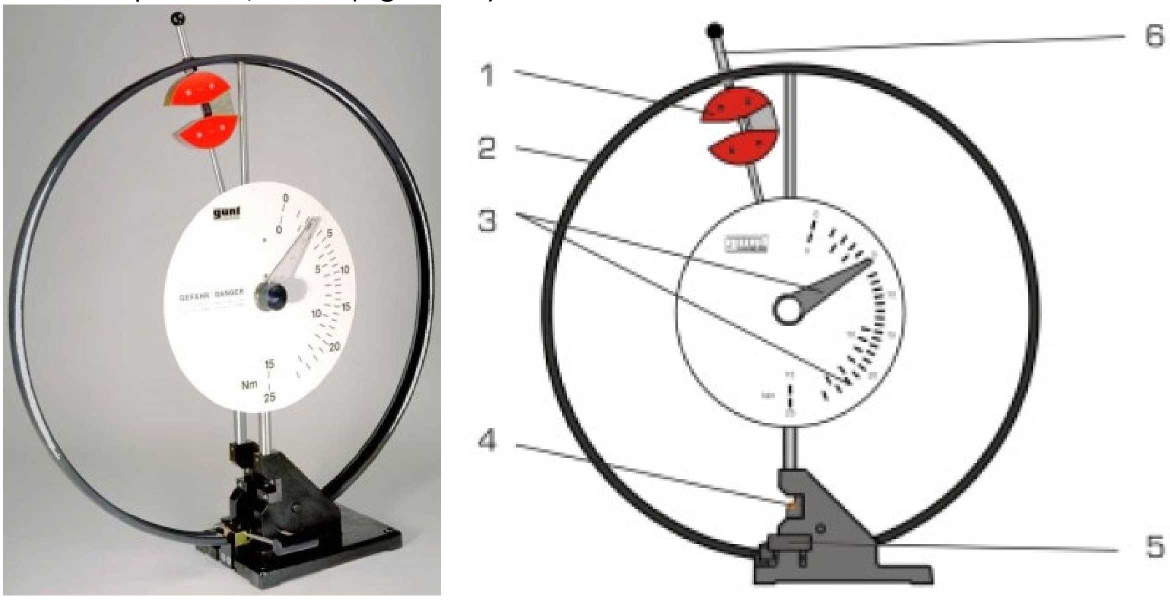


Figure 5.2 WP 400-Impact test, 25Nm
, 1 hammer with removable additional weights, 2 protective ring, 3 scale with drag pointer, 4 notched bar impact specimen, 5 two-hand trigger and brake, 6 hammer fixing

5-6Test specimens:

Specimens for Charpy notched-bar impact test specimens , accessory for WP 400 Impact test,
25Nm machine is shown in figures 5.3 , 5.4 ,5.4

figure 5.3 notched-bar impact specimens form: ISO-V LxWxH: 55x5x10mm notch radius: 0,25mm , material: construction steel

figure 5.4 notched-bar impact specimens form: ISO-V , LxWxH: 55x5x10mm ,notch radius: 0,25mm ,material: brass

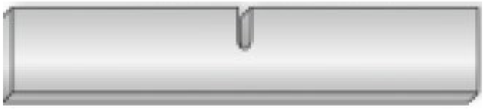


figure 5.5 notched-bar impact specimens form: ISO-U, LxWxH: 55x5x10mm ,notch radius: 1mm , material: free cutting steel

5-7 Procedure:

1) The specimen is attached the grips of the testing machine.

2) In the experiment, the hammer attached to a pendulum arm describes an arc. At the lowest point of the hammer path, the hammer transfers part of its kinetic energy to the notched specimen, take up the hammer fixing to late the hammer of fall The specimen is pulled to failure. Figure 4.6

3) Record the reading from the scale with trailing pointer, its impact work A_k

$$A_k = mg(H-h)$$

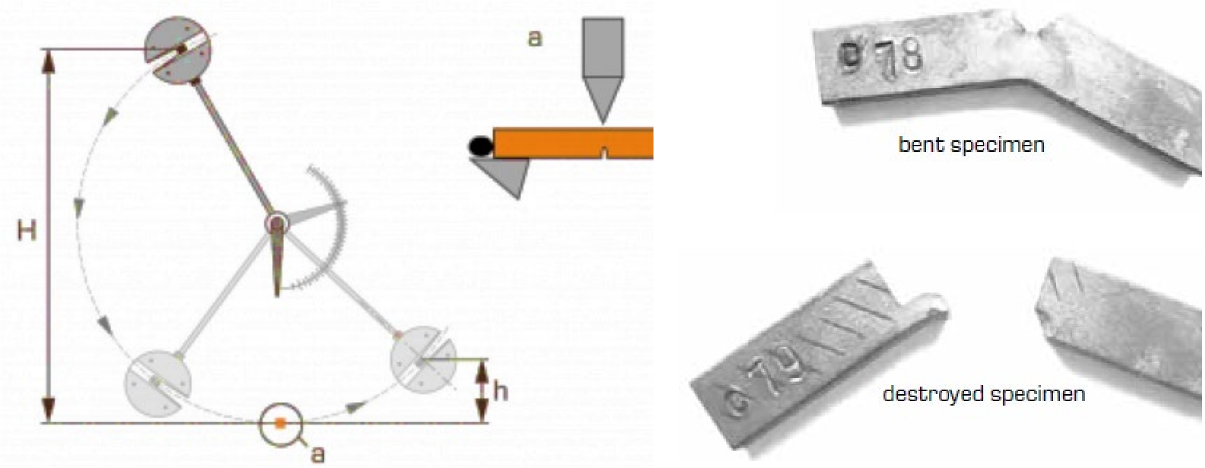


Figure 4.6 Principle of operation of the Charpy notched bar impact test: H height of fall, h height of rise, a hammer and specimen, plan view

4) Calculate the **impact strength q** , from equation :

$$q = \frac{A_k}{S_0}$$

Notes

In the experiment, the hammer attached to a pendulum arm describes an arc. At the lowest point of the hammer path, the hammer transfers part of its kinetic energy to the notched specimen. The specimen is either destroyed or bent by the impact and pushed between the supports. The notched-bar impact work required to deform the specimen is read directly off a large scale. By using the WP 400.20 system for data acquisition, the measured values can be transferred to a PC where they can by analysed with the software. In order to vary the output energy, the mass of the hammer can be changed by adding or removing weights. A brake reduces the residual energy of the hammer on each swing until it reaches zero. A protective ring ensures the experiments can be conducted safely while also fixing the hammer in place. The hammer is triggered with two hands for safer operation. A protective cover for the WP 400.50 operating area is available as an accessory. The experimental results allow quality control and an analysis of the fracture behaviour of different metallic materials. Non-metallic specimens can also be used. Specimens with different notch geometries, in different materials and specimen dimensions are included in the scope of delivery

6-Laboratory 5: Bending tests

6-1 Introduction

The most frequently studied bending load in materials testing is the three-point bending test. Using this method, a beam mounted on two supports is studied under a single force applied to the centre. The bending test demonstrates the relationship between the load of a bending beam and its elastic deformation. The effects of modulus of elasticity and second moment of area are shown figure 6.1

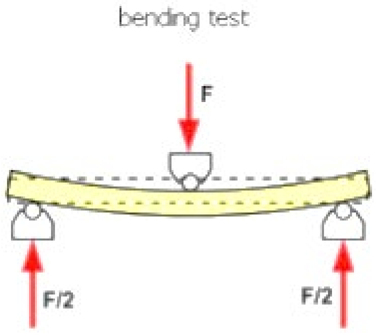


Figure 6.1 a- Test process in the three-point bend test

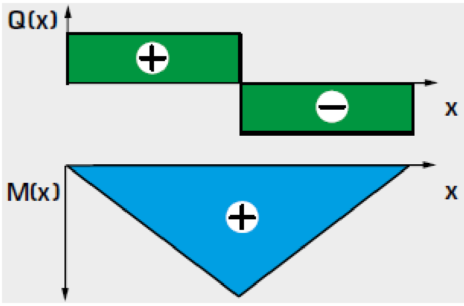


Figure 6.1 b- Bending stress with profile of shear forces and bending moment Q shear force, M bending moment, x distance

6-2 Objective:

1- Loading of a bending beam by a point force and Students are able to explain load-deflection relationships and represent them in graphical forms (load - deflection curve).
2- influence of modulus of elasticity E and second moment M_x of area on elastic deformation

6-3 The machine used to Bending tests: WP 300 Universal testing machine (figure 6.2)

Figure 6.2 a WP 300 Universal testing machine

6-2 b Bending test device

6-5Test specimens:

Specimen, flat steel cold drawn

• Cross-section: 40x10mm

• Length: 320mm

Support distance: 100···300mm

6-6 Procedure:

1- Place the specimen in designated space (special place) in machine (Figure 6.2).

2- Loading of a bending beam by a point force (the load is increased gradually) figure 6.3 and record the load and deflection in table 5.1.

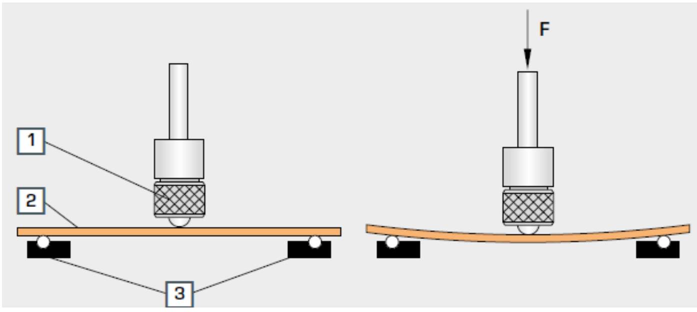


figure 6.3 Test process in the three-point bend test

1 pressure piece, 2 specimen, 3 two supports on which the beam is mounted, F test load

3- calculate the second moment of area by formula 5.1

$$M_X = \frac{PL}{4}$$

4- Calculate the centroidal moment of inertia of the rectangular cross section by formula 5.2

$$I_X = \frac{bh^3}{12} \qquad 5.2$$

5- Calculate the Steers from the formula 5.3

$$\sigma = \frac{M_X}{I_X} y \qquad 5.3$$

6- Calculate modulus of elasticity E using the formula 5.4

$$\delta = \frac{PL^3}{48EI} \qquad 5.4$$

7- Plot the diagram load-deflection(P-δ)

Table 5.1

Number	Load P, kN	Dial reading mm	Deflection δ, cm	Stress ,kN/cm² $\sigma = \quad PL$	Modulus of Elasticity E kN/cm²
1	0				
2	1				
3	2				
4	3				
5	4				
6	5				
7	6				
8	7				
9	8				

7-Laboratory 6: Hardness tests

7-1 Introduction:

Hardness refers to the mechanical resistance with which a body opposes the intrusion of another body.

7-2 Principle of the Brinell hardness test

In this test method, a standardized test body – a hard metal sphere – is pressed into the workpiece under defined conditions. The surface of the lasting impression is then measured optically. The impression surface is calculated from the impression diameter and the sphere diameter. A triaxial stress state develops in the specimen, underneath the impressing test body.

7-3 Objective:

The objective of this experiment is to determine the hardness of material.

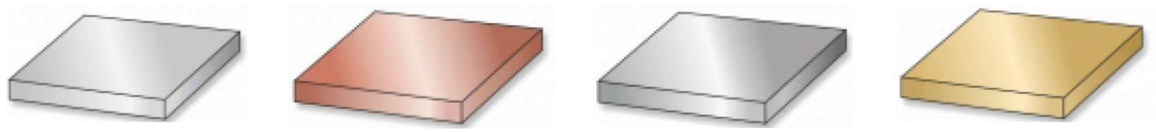
7-4 The machine used to hardness tests:

WP 300 Universal testing machine (figure 7.1)

Figure 7.1 WP 300 Universal testing machine

7-5 Test specimens:

- Four specimens made of: aluminium, copper, brass, steel- figure 7.2
- The specimen dimensions are LxWxH: 30x30x10mm



Al Cu St Zn

figure 7.2

7-6 Procedure:

1- The specimen is located in to the special place in the testing machine.
2- Loading of specimen by a point force (the load is 10KN for 15-30 second).

3- Measure the Diameter of the impression surface of the spherical segment (d) Figure 7.3 and record it in table 5.1.

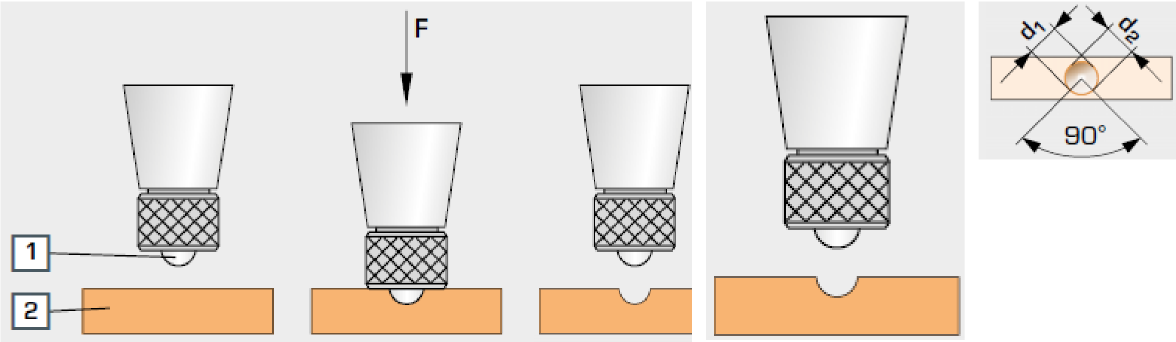


Figure 7.3 Brinell hardness test
1 hardened steel ball, 2 specimen; F test load, d_1 and d_2 dimensions of the impression surface(perpendicular to each other)

4- The Brinell hardness is calculated from the test load and impression surface of the spherical segment.

$$HB = \frac{0.2F}{\pi(D - \sqrt{D^2 - d^2})}$$

Where:

HB -Brinell hardness value,

F -Test load in N,

D- Diameter of the spherical segment (D =…………………mm)

d- Diameter of the impression surface of the spherical segment.

Table 4.1

Sample	F , kN	D , mm	d ,mm	HD
Aluminum	10			
Bronze	10			
Steel	10			
Copper	10			

8-Laboratory 7: Buckling behavior of bars

8-1 Objective:

1- investigation of buckling behavior under the influence of
   - ✓ different supports and clamps
   - ✓ different bar lengths and cross-sections
   - ✓ different materials
   - ✓ additional lateral load

2- testing Euler’s theory: buckling on elastic bars

3- calculating the expected buckling force with Euler’s formula

4- graphical analysis of the deflection and the force

5- determine elastic modulus for an unknown material (GFRP)

6- measure force and deflection

7- with the WP 120.01 expansion set investigation of buckling behavior under the influence of

8- different cross-section shapes

9- eccentric application of force

8-2 The machine used to Buckling tests**:** WP 120 Buckling behavior of bars (figure 8.1)

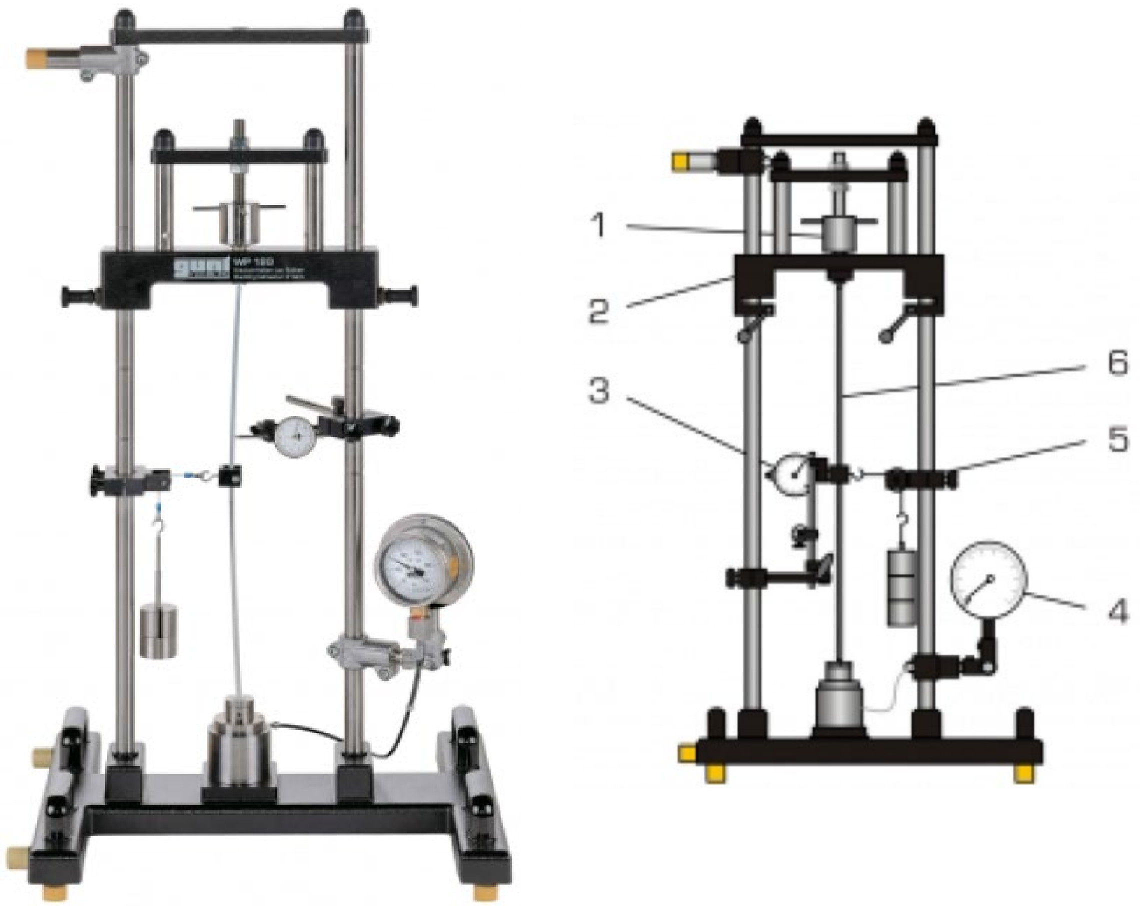
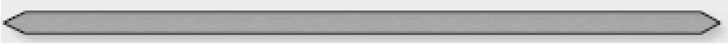
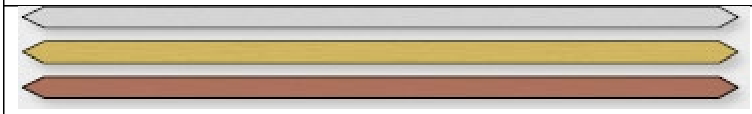
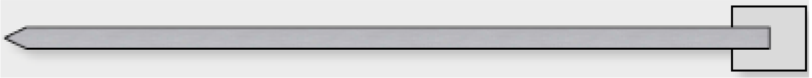
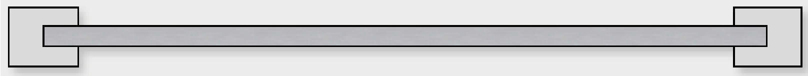


Figure 8.1 a WP 120 Buckling behavior of bars
1 spindle, 2 height-adjustable load member, 3 dial gauge for lateral deflection of the test bar,4 dynamometer, 5 mechanism for generating a lateral load, 6 test bar

8-3Test specimens:

WP 120 contains the following test bars:

 **Flat bar**	Pinned end/pinned end ✓ Cross-section: 20x4 mm ✓ Bar length in mm: 350, 500, 600, 650, 700 ✓ Material: St
 **Flat bar**	Pinned end/pinned end ✓ Cross-section: 25x6 mm ✓ Bar length: 600mm ✓ Material: Al, CuZn, Cu
 **Flat bar**	Pinned end/pinned end ✓ Cross-section: 25x10mm, ✓ bar length: 600mm ✓ Material: GRP
 **Flat bar**	Pinned end/fixed end ✓ Cross-section: 20x4mm, ✓ bar length: 650mm ✓ Material: St
 **Flat bar**	Fixed end/fi xed end ✓ Cross-section: 20x4mm, ✓ bar length: 650mm ✓ Material: St

8-4Euler's buckling cases Figure 8.3

The mathematician and physicist Leonhard Euler defined four typical buckling cases to calculate the buckling force. For each of these cases, there is a buckling length coefficient β that is used to determine the buckling length LK.

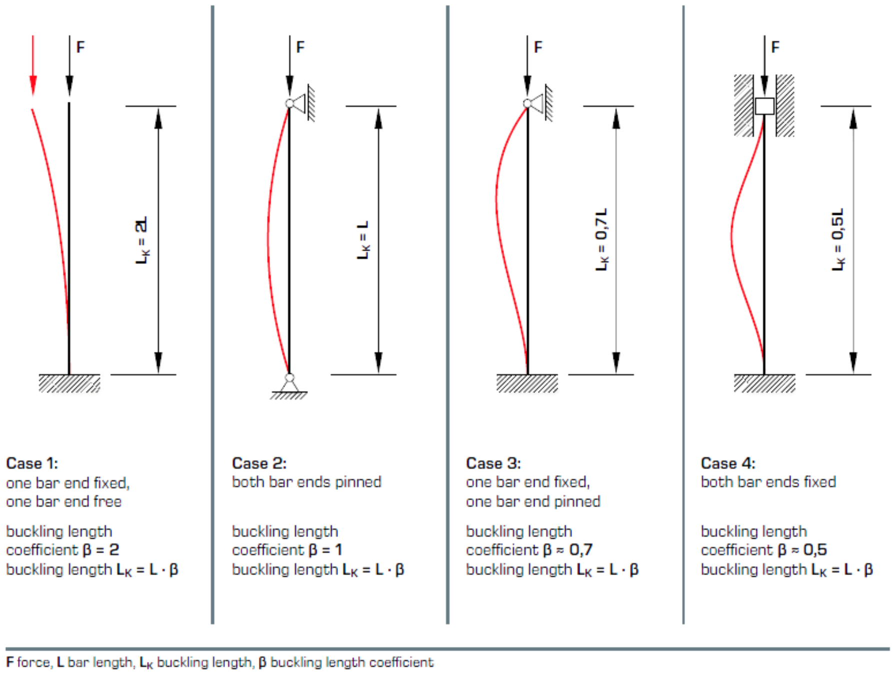


Figure 8.3 Euler's buckling cases

8-6 Procedure:

1- The specimen is attached the grips of the testing machine (Figure 8.2).

2- Loading of test bar by a point force (the load is increased gradually) and record the load and deflection in table 8.1.

3- Plot the diagram load-deflection(P-Δ) and find the laboratories' P_{cr}.

4- Calculating the expected buckling force with Euler's formula P_{cr}.

$$p_{cr} = \frac{\pi^2 \, E \, I_y}{l_k^2}$$

Where :

P_{cr} -critical buckling force

- l_k - equivalent buckling bar length
- E - elastic modulus,
- I - axial second moment of the cross-section area

Table 8.1

Load, p.N													
Δ													

Experiments described as per Al-Baha University Curriculum for Soil laboratory.

1-Sieve Analysis Test:

Purpose**:** The standard grain size analysis test determines the relative proportions of different grain sizes as distributed among certain size ranges.

Equipment:

1) Balance (degree of accuracy is 1gm).
2) Set of sieves.
3) Cleaning brush.
4) Sieve shaker.
5) Mixer (blender.
6) Timing device.

Test procedure:

1- Record the weight of the given dry soil sample.

2- Make sure that all the sieves are clean and assemble them in the ascending order of sieve numbers (#4sieve at top and #200sieve at bottom). Place the pan below #200 sieve Carefully pour the soil sample into the top sieve and place the cap over it.

3- Place the sieve stack in the mechanical shaker and shake for 5 minutes.

4- Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

5- Obtain the mass of soil retained on each sieve by using the balance, and record this mass as the weight retained on the data sheet. The sum of these retained masses should be approximately equals the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.

6- Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample mass.

7- Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

8- Make a semi-logarithmic plot of grain size vs. percent finer.

9- Compute C_c and C_u for the soil.

The students were able to conclude the following:

1. Calculate the percent passing from sieve.
2. Make a semi-logarithmic plot of grain size vs. percent finer.
3. Compute Cc and Cu for the soil.

2-Constant Head Permeability test

Purpose: Determination of the Coefficient of Permeability (k) of coarse sand.

Equipment:

1. Constant head permeameter
2. Graduated flask
1- Sensitive balance (degree of accuracy is 0.1 gm.).
2- Stopwatch
3- Porous stones.

Test Procedure:

1- The sand has been filled and the permeameter is all set prior to the class.
2- Allow water to flow through the funnel until the water level in the funnel is constant.
3- Open the bottom outlet, run water through the perimeter until the sand is saturated and no air bubbles appear to flow out of the discharge pipe (steady flow).
4- Measure the head of water (h), distance between the water surface in the funnel and the bottom outlet of the perimeter (fill in column 4 of the table).
5- Run the water with the bottom outlet open for some time to achieve steady state (no air bubbles flowing through the pipe) at that particular height.
6- Use graduated jar to collect the discharge water.
7- Start the stopwatch and collect the discharge water in the graduated jar for a particular period (say 3 minute), record the time of collection (column 3 of the table).
8- Record the volume of water from the graduated jar (column 2 of the table).
9- Repeat steps 4 to 10 three times and calculate the average k (cm/s)

The students were able to conclude the following:

1.Carry out the Permeability test.

2. Determination of the Coefficient of Permeability (k) of coarse sand.

3-Falling Head Permeability test

Purpose: To determine the Coefficient of Permeability (k) of the soil of low Permeability as fine soil (Silt and Clay).

Equipment:

1- head perimeter,
2- Graduated flask,
3- Sensitive balance (degree of accuracy is 0.1 gm.).
4- Stopwatch.
5- Porous plates.

Test Procedure:

1- Compact the sample in the lower chamber section of the perimeter, in layers approximately 1.5 cm deep, to within about 2 cm of the lower chamber rim. Use an appropriate tamping device to compact the sample to the desired density.
2- Remove the upper section of the chamber tie rods and place the upper porous stone on the specimen, securing the upper section of the chamber with spring to the unit.
3- Measure and record the length and the diameter of the specimen.
4- Use the clamp to attach the falling head burette to the support rod. Position the burette as high as is possible for practicality. Place the meter stick directly behind the burette, so the height of water in the burette above the chamber outflow port may be read.
5- Saturate the specimen, following the steps outlined above.
6- Measure the heights of the two levels from the outflow level.

The students were able to conclude the following:

1.Carry out the Permeability test.

2.Determine the Coefficient of Permeability (k) of Silt and Clay soil.

4- Liquid Limit test

Equipment:

1- Casagrande device,
2- Porcelain (evaporating) dish,
3- Flat grooving tool with gage,
4- Moisture cans,
5- Balance (accuracy 0.1 gm),
6- Spatula,
7- Wash bottle filled with distilled water,
8- Drying oven set at 105°C.

Test Procedure:

1- Use potion of soil passing sieve #40 (0.425 mm).
2- Mix soil with water to form a paste.
3- Place in cup using spatula.
4- Make a groove using a grooving tool.
5- Rotate the cam at approximately 2 revolutions per second.
6- Record the number of blows (N) required to close a gap of 13 mm at the bottom.
7- Take asample from the soil and get it's water content (W.C)
8- A- If (N > 25) then W.C < L.
9- Plote the point on the semi log graph (W.C versus N) and draw the flow curve as the line of best fit.
10-Get (L.L) [water conent corresponding to N=25 blows] from the graph.

The students were able to conclude the following:

1- Determine the Liquid limit of the soil, after which the soil start behaves as viscous fluid.

5- Plastic Limit test

Equipment:

1- Soil specimen
2- Moisture cans
3- Glass plate
4- Spatula
5- Oven
6- Balance (accuracy 0.1 gm).

Procedure:

1- Use portion of soil passing from sieve # 40 (0.425 mm).
2- Take about 30 gm of soil and mix with water.
3- Take about 10 gm and form a ball.
4- Roll the fingers on a glass plate to a thread.
5- A- If the thread cracked at diameter > 3mm then W.C $<$ P.L,
Mix the paste with some additional water and repeat steps 3 to 4.
B- If the thread cracked at diameter < 3mm then W.C $>$ P.L,
Allow soil to dry in air and repeat steps 3 to 4 .
6- Repeat the above steps until the thread cracks at diameter 3mm.
7- Get W.C of the soil that cracked to be the plastic limit .

The students were able to conclude the following:

1- Determine the plastic limit, It is the water content at which the soil begins to crumble when rolled into threads of diameter 3 mm.

6-Unconfined Compression Test

Purpose: The primary purpose of this test is to determine the unconfined compressive strength

Equipment: Unconfined compression testing machine.

Test Procedure:

1. Extrude the undisturbed soil sample from the sampler (Shelby tube) then determine the type of soil, initial moisture content and the specific gravity of the soil.
2. Weigh the empty consolidation ring together with plate.
3. Place the sample on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring as in figure 32. Rotate the ring and pare off the excess soil by means of the cutting tool so that the sample is reduced to the same inside diameter of the ring as in figure 33, make sure that there is no void space between the sample and the ring.
4. Measure the height (Hi) of the ring and it's inside diameter (d) and weigh the specimen plus ring plus plate.
5. Center the porous stones on the top and bottom surfaces of the test specimen. Place the filter papers between porous stones and soil specimen. Press very lightly to make sure that the stones adhere to the sample. Lower the assembly carefully into the base of the water reservoir. Fill the water reservoir with water until the specimen is completely covered and saturated.
6. To prevent movement of the ring and porous stones, place the load plate centrally on the upper porous stone and adjust the loading device.
7. Adjust the dial gauge to a zero reading and record the consolidation dial readings with the times.
8. Use different pressures include load 5, 10, 20, 40, 80, 160, 320 and 640 Kg/m2 with reading time each 15 sec.

The students were able to conclude the following:

1- Determine the unconfined compressive strength (q_u).

7-Poocket test

Purpose: Used to determine the unconfined compression strength for undisturbed samples.

Equipment:

1- Smooth spatula,
2- Graduated device to measure the unconfined comprssion strength.

Test Procedure:

1- Put the graduated device perpendicular to the sample surface.
2- Press on a certain point on the surface to a certain sign on the graduated device.

The students were able to conclude the following:

1- Determine the unconfined compression strength.

8-Consolidation Test

Equipment:

1- Consolidation (Odometer) cell: (ring, porous stones, water reservoir, and load plate),
2- Loading arm with base and weights.
3- Dial gauge to measure compression or swelling of the sample.

Test Procedure:

1- Extrude the undisturbed soil sample from the sampler (Shelby tube) then determine the type of soil, initial moisture content and the specific gravity of the soil.
2- Weigh the empty consolidation ring together with plate.
3- Place the sample on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring as in figure 32. Rotate the ring and pare off the excess soil by means of the cutting tool so that the sample is
4- reduced to the same inside diameter of the ring as in figure 33, make sure that there is no void space between the sample and the ring.
5- Measure the height (Hi) of the ring and it's inside diameter (d) and weigh the specimen plus ring plus plate.
6- Center the porous stones on the top and bottom surfaces of the test specimen. Place the filter papers between porous stones and soil specimen. Press very lightly to make sure that the stones adhere to the sample. Lower the assembly carefully into the base of
7- the water reservoir. Fill the water reservoir with water until the specimen is completely covered and saturated.
8- To prevent movement of the ring and porous stones, place the load plate centrally on the upper porous stone and adjust the loading device.
9- Adjust the dial gauge to a zero reading and record the consolidation dial readings with the times.
10- Use different pressures include load 5, 10, 20, 40, 80, 160, 320 and 640 Kg/m2 with reading time each 15 sec.

The students were able to conclude the following:

1- Determine the magnitude and rate of volume decrease of clay soil.

Experiments described as per Al-Baha University Curriculum for Fluid Mechanics and Hydraulics Laboratory.

1. Experiment Title : Determination of Density, Specific Weight, Specific Volume, Relative Density and Specific Gravity of Solids

- **Objective:** Determination of Density, Specific Weight, Specific Volume, Relative Density and Specific Gravity of Aluminum, Brass and Poly Oxy methylene
- **Equipment:** Solid cylinders of Aluminum, Brass and Poly Oxy methylene, balance & Ruler.
- **Procedure** find the following:
  a. Weight in Newton using the balance
  b. Dimensions of the material sample using the ruler
  c. From the weight find the mass of the material
  d. From the dimensions find the volume of the sample
- **Calculations and Results**:
  a. Find the density of the material: ρ = Mass/Volume
  b. Find the specific Weight of the material: γ = Weight/Volume
  c. Find the specific volume = 1/ρ
  d. Find the relative density of the material : r.d. = ρ/ρ_{water}
  e. Find the specific gravity of the material: S.G = γ / γ_{water}

2. Experiment Title: Determination of Density, Specific Weight, and Relative Density of Liquids using Pressure

- **Objective:** Determination of Density, Specific Weight, and Relative Density of Tap water using Pressure
- **Equipment:** Water tank, Submersible Pump, Pipework and valves, transparent graduated cylinder, pressure sensor and screen.
- **Procedure**:
  a. Put the electric power "ON"
  b. Operate the water pump.
  c. Pump water to the transparent cylinder to a certain height (say 40 cm)
  d. Read and record the pressure reading (in mbar) on the screen
  e. Open the valve gradually to enable water to drain from the cylinder such theat water level goes down by 5 cm
  f. Read and record the new pressure (in mbar) reading on the screen
  g. Repeat the previous step until the water height is 5cm
- **Calculations and Results**:
  a. Change the pressure (P) readings from mbar to Pascal (N/m^2)
  b. Change the water heights from centimeters meters (H)
  c. Find the specific Weight of the material: γ = Pressure /Height
  d. Find the Density of Fluid ρ = γ/g
  e. Find the specific volume = 1/ρ
  f. Find the relative density of the material : r.d. = ρ/ρ_{water}
  g. Find the specific gravity of the material: S.G = γ / γ_{water}

3. Experiment Title: Surface Tension, , Head& Pressure, and Pressure using Different Shapes of Tubes

- **Objective:** observe the Surface Tension, , Head& Pressure, and Pressure using Different Shapes of Tubes
- **Equipment:** Different diameters of vertical glass tubes connected together via a horizontal tube, Different shapes of vertical glass tubes connected together via a horizontal tube, set of four shapes of glass tubes
- **Procedure**:

i. Using Different diameters of vertical glass tubes connected together via a horizontal tube
   a. Pour water in the largest diameter tube.
   b. Notice the water level in smaller diameter tubes

ii. Different shapes of vertical glass tubes connected together via a ntal tube
   c. Pour water in each tube to predetermined level
   d. Notice the water level in the other different shapes tubes

iii. set of four shapes of glass tubes
   e. Pour water in each tube to predetermined level
   f. Read the value on of pressure on the pressure meter

- **Calculations and Results**:

a. Surface Tension Experiment: Water height should be inversely proportional to the diameter.
b. Head and Pressure Experiment: water level should be the same in all different diameters pipes.
c. Pressure using different shapes of tubes Experiment: Pressure should be the same for each water height irrespective of the shape of tube.

4. Experiment Title: Determination of Discharge (Q)

- **Objective:** Determination of Discharge
- **Equipment:** Lower Water tank, Submersible Pump, Pipework and valves, graduated upper water tank, Stop watch.
- **Procedure**:
  a. Put the electric power "ON"
  b. Operate the water pump.
  c. Close the valve connecting the upper and lower water tanks and operate the stop watch simultaneously
  d. Read and record the cumulative volume and Time
- **Calculations and Results**:
  a. Find Δt and ΔV
  b. For each time step Δt and ΔV find the discharge = $\Delta V / \Delta t$
  c. Find the average discharge for all steps

5. **Experiment Title: Flow over Sharp Crested Weir**

- **Objective:** Determination of the coefficient of discharge for the Sharp Crested Weir
- **Equipment:** Sharp crested weir on rectangular channel, Lower Water tank, Submersible Pump, Pipework and valves, graduated upper water tank, Stop watch.
- **Procedure**:
  a. Put the electric power "ON"
  b. Operate the water pump.
  c. Find the discharge as per experiment (4)
  d. Measure and record the width of channel
  e. Measure and record the water depth before the weir
  f. Measure and record the height of the weir

- **Calculations and Results**:
  d. Estimate the total head above the weir
  e. Equate the discharge found in step "C" above to the flow over the weir
  f. Using the equation of the weir find the discharge coefficient (C_d).

6. Experiment Title: Demonstration of Bernoulli Principle

- **Objective:** Demonstration of Bernoulli Principle
- **Equipment:** Venturi-meter, Lower Water tank, Submersible Pump, Pipework and valves, six piezometers fixed in the venturi-meter, pitot tube, Total head piezometer.
- **Procedure**:
  a. Put the electric power "ON"
  b. Operate the water pump.
  c. Find the discharge as per experiment (4)
  d. Move the pitot tube sensor to first piezometer
  e. Read the water level on the first piezometer.
  f. Read the water level on the total head piezometer.
  g. Repeat the steps c,d,e for the remaining five piezometers.
  h. Record the cross-sectional area of the venturi at each piezometer.
- **Calculations and Results**:
  i. Find the pressure head at each piezometer: $P = \gamma h$
  j. Find the velocity head at each piezometer= Total head –pressure head
  k. Find the velocity of water at each piezometer
  l. Find the velocity of water at each piezometer using the continuity equation= Q/A
  m. Compare the velocities found in steps K and I
  n. Draw the profile of the total head
  o. Draw the profile of the pressure head
  p. Draw the profile of the velocity head.

7. Experiment Title: Head losses in Valves and Fittings

- **Objective**: Find the head losses and loss coefficient in valves and fittings.
- **Equipment:** Venturi-meter, Lower Water tank, Submersible Pump, Pipework and valves, six piezometers fixed in the venturi-meter, pitot tube, Total head piezometer.
- **Procedure**:
    a. Put the electric power "ON"
    b. Operate the water pump.
    c. Find the discharge as per experiment (4)
    d. Read the water level on the piezometers before and after the fittings or valve.
    e. Record the cross-sectional area of at each fittings or valve.

- **Calculations and Results**:
    a. Find the velocity of flow at each fittings or valve
    b. Find the head loss at each fittings or valves= head before–head after
    c. Find the head loss coefficient

8. Experiment Title: Flow over Sharp Crested Weirs and Hydraulic Jump

- **Objective**: Find the Characteristics of a Hydraulic Jump
- **Equipment:** Sharp crested weir on rectangular channel, Lower Water tank, Submersible Pump, Pipework and valves, graduated upper water tank, Stop watch.
- **Procedure**:
    a. Put the electric power "ON"
    b. Operate the water pump.
    c. Find the discharge as per experiment (4)
    d. Adjust the flow and channel to form a hydraulic jump.
    e. Measure the water depth before the weir, after the weir and after the jump.
- **Calculations and Results**:
    a. Find the velocity of flow before the weir, after the weir and after the jump.
    b. Find Froude number before the weir, after the weir and after the jump.
    c. Determine the type of jump, head loss in jump and efficiency of the jump.

9. Experiment Title: Flow over Broad Crested Weirs and Hydraulic Jump

- **Objective**: Find the Characteristics of a Hydraulic Jump
- **Equipment:** Broad crested weir on rectangular channel, Lower Water tank, Submersible Pump, Pipework and valves, graduated upper water tank, Stop watch.
- **Procedure**:
    a. Put the electric power "ON"
    b. Operate the water pump.
    c. Find the discharge as per experiment (4)
    d. Adjust the flow and channel to form a hydraulic jump.
    e. Measure the water depth before the weir, after the weir and after the jump.
- **Calculations and Results**:
    a. Find the velocity of flow before the weir, after the weir and after the jump.
    b. Find Froude number before the weir, after the weir and after the jump.
    c. Determine the type of jump, head loss in jump and efficiency of the jump.

10. Experiment Title: Manning's and Chezy's Normal Flow Equations

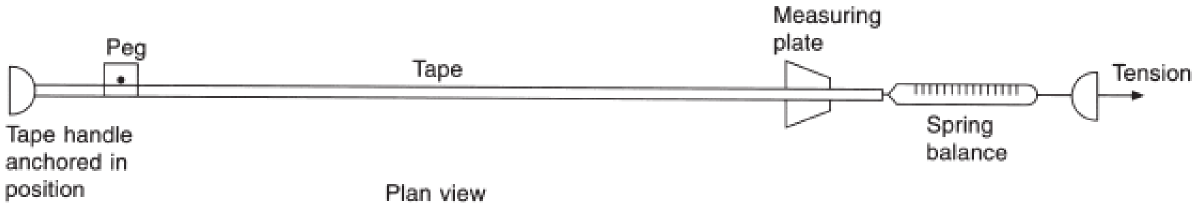
- **Objective**: Find the Manning's and Chezy's Coefficients for Normal Flow
- **Equipment:** rectangular channel, Lower Water tank, Submersible Pump, Pipework and valves, graduated upper water tank, Stop watch.
- **Procedure**:
    a. Put the electric power "ON"
    b. Operate the water pump.
    c. Find the discharge as per experiment (4)
    d. Measure the width of channel
    e. Measure the average water depth in the channel
- **Calculations and Results**:
    a. Find the Channel Parameters i.e. hydraulic radius, wetted perimeter and slope of water level
    b. Find Manning's "n"
    c. Find Chezy's C

Experiments described as per Al-Baha University Curriculum for Surveying laboratory.

Measuring along the ground

The most accurate way to measure distance with a steel band is to measure the distance between pre-set measuring marks, rather than attempt to mark the end of each tape length. The procedure is as follows:

1. The Surveying points to be measured are defined by nails in pegs and should be set flush with the ground surface. Ranging rods are then set behind each peg, in the line of measurement.



2. Using a linen tape, arrows are aligned between the two points at intervals less than a tape length. Measuring plates are then set firmly in the ground at these points, with their measuring edge normal to the direction of taping.
3. The steel band is then carefully laid out, in a straight line between the Surveyingpoint and the first plate. One end of the tape is firmly anchored, whilst tension is slowly applied at the other end. At the exact instant of standard tension, both ends of the tape are read simultaneously against the Surveying station point and the measuring plate edge respectively, on command from the person applying the tension. The tension is eased and the whole process repeated at least four times or until a good set of results is obtained.
4. When reading the tape, the meters, decimetres and centimetres should be noted as the tension is being applied; thus, on the command 'to read', only the millimeters are required.
5. The readings are noted by the booker and quickly subtracted from each other to give the length of the measured bay.
6. In addition to 'rear' and 'fore' readings, the tape temperature is recorded, the value of the applied tension, which may in some instances be greater than standard, and the slope or difference in level of the tape ends are also recorded.
7. This method requires a Surveying party of five; one to anchor the tape end, one to apply tension, two observers to read the tape and one booker.
8. The process is repeated for each bay of the line being measured, care being taken not to move the first measuring plate, which is the start of the second bay, and so on.

9. The data may be booked as follows:

Line	Fore-distance	Back-distance	Mean	Remarks
AB				
BC				
CD				
DA				
AC				
BD				

10. Plot measurements using suitable scale.

Measuring Linear Distance Using Laser Distometer

1. Make the required reconnaissance,
2. Set up the instrument:
    a. The required units
    b. The required values such as Lengths, Areas, or Volumes ect.
    c. Repeat.

Theodolite Temporary Adjustment

The methods of setting up the theodolite and observing angles will now be dealt with. It should be emphasized, however, that these instructions are no substitute for practical experience.

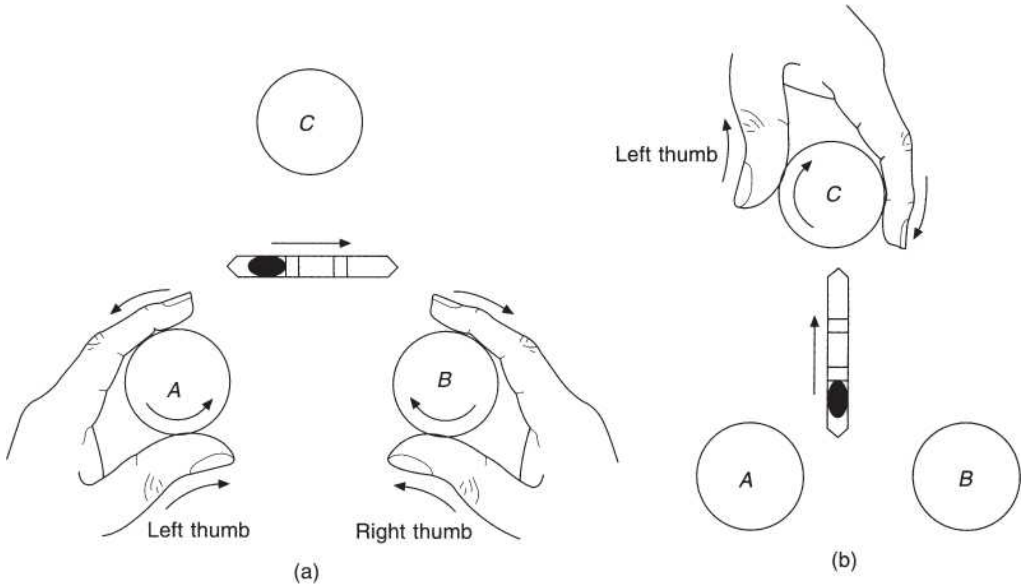
Setting up using a plumb-bob

1. Extend the tripod legs to the height required to provide comfortable viewing through the theodolite. It is important to leave at least 100 mm of leg extension to facilitate positioning of the plumb-bob.
2. Attach the plumb-bob to the tripod head, so that it is hanging freely from the center of the head.
3. Stand the tripod approximately over the surveying station, keeping the head reasonably horizontal.
4. If the tripod has them, tighten the wing units at the top of the tripod legs and move the whole tripod until the plumb-bob is over the station.
5. Now tread the tripod feet firmly into the ground.
6. Unclamp a tripod leg and slide it in or out until the plumb-bob is exactly over the station. If this cannot be achieved in one movement, then use the slide extension to bring the plumb-bob in line with the Surveyingpoint and another tripod leg. Using this latter leg, slide in or out to bring the plumb-bob onto the Surveyingpoint.
7. Remove the theodolite from its case and hold it by its standard, attach it to the tripod head.
8. The instrument axis is now set truly vertical using the plate bubble as follows:

    a. Set the plate bubble parallel to two-foot screws A and B and center it by equal amounts of simultaneous contra-rotation of both screws. (The bubble follows the direction of the left thumb.)
    b. Rotate alidade through 90° and Centre the bubble using foot screw C only.
    c. Repeat (a) and (b) until bubble remains central in both positions. If there is no bubble error this procedure will suffice. If there is a slight bubble error present, proceed as follows.
    d. From the initial position at B, rotate the alidade through 180°; if the bubble moves off-center bring it halfway back using the footscrews A and B.

e. Rotate through a further 90◦, placing the bubble 180◦ different from its position. If the bubble moves off-center, bring it halfway back with footscrew C only.
f. Although the bubble is off center, the instrument axis will be truly vertical and will remain so as long as the bubble remains the same amount off center.
g. Test that the instrument has been correctly levelled by turning the instrument to any arbitrary direction. If the instrument is correctly levelled the bubble will remain in the same position within its vial no matter where the instrument is pointed.

9. Check the plumb-bob; if it is off the Surveyingpoint, slacken off the whole theodolite and shift it laterally across the tripod head, taking care not to allow it to rotate until the plumb-bob is exactly over the Surveyingpoint.
10. Repeat (8) and (9) until the instrument is centered and levelled.



Setting up using the optical plumb-bob

All modern instruments have an optical plummet built into the alidade section of the instrument (Figures (a)), or into the tribrach. Proceed as follows:

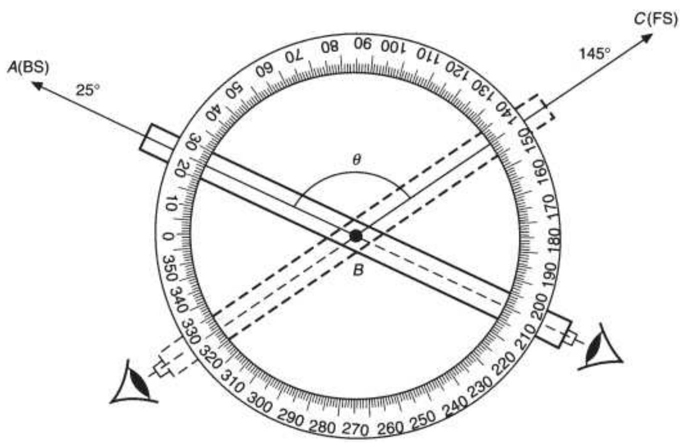
1. Establish the tripod roughly over the Surveyingpoint using a plumb-bob as in (1) to (5) above.
2. Depending on the situation of the optical plummet, attach the tribrach only, or the theodolite, to the tripod.
3. Using the footscrews to incline the line of sight through the plummet, center the plummet exactly on the Surveyingpoint.
4. Using the leg extension, slide the legs in or out until the circular bubble of the tribrach/theodolite is exactly Centre. Even though the tripod movement may be excessive, the plummet will still be on the surveying point. Thus, the instrument is now approximately centered and levelled.
5. Precisely level the instrument using the plate bubble, as described in (8) of above. Unclamp and move the whole instrument laterally over the tripod until the plummet crosshair is exactly on the Surveyingpoint.
6. Repeat (5) and (6) until the instrument is exactly centered and levelled.

Horizontal Angle Measurement

Although the theodolite or total station is a very complex instrument the measurement of horizontal and vertical angles is a simple concept. The horizontal and vertical circles of the instrument should be regarded as circular protractors graduated from 0o to 360o in a clockwise manner. Then a simple horizontal angle measurement between three surveying points A, B, and C in the sense of measuring at A clockwise from B to C would be as shown in Figure below.

1. The instrument is set up centered and levelled on Surveyingpoint *B*. Parallax is removed.
2. Commencing on, say, ‘face left’, the target set at Surveyingpoint *A* is carefully bisected and the horizontal scale reading noted = 25^{o}.
3. The instrument is rotated to Surveyingpoint *C* which is bisected. The horizontal scale reading is noted = 145 ^{o}.
4. The horizontal angle is then the difference of the two directions, i.e. Forward Station (C) minus Back Station (A), (FS - BS) = (145^{o} - 25^{o}) = 120^{o}.
5. Change face and observe Surveyingpoint *C* on ‘face right’ and note the reading = 325^{o}.
6. Swing to point A and note the reading = 205^{o}.
7. The readings or directions must be subtracted in the same order as in (4), i.e. *C — A.*

Thus (325o — 205o) = 120o

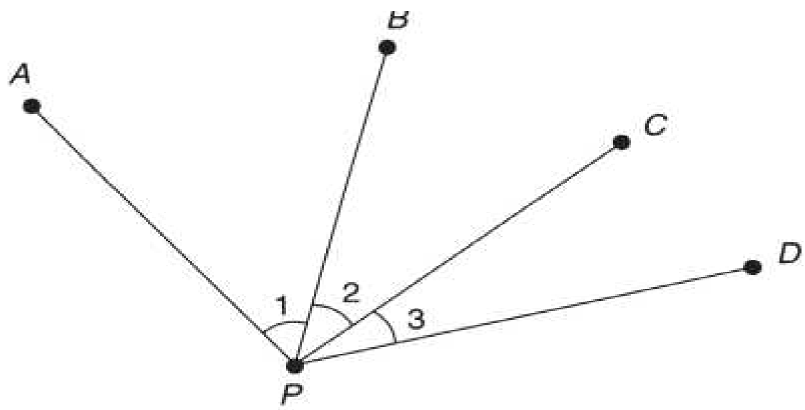


8. Note how changing face changes the readings by 180°, thus affording a check on the observations. The mean of the two values would be accepted if they are in good agreement.
9. Try to use the same part of the vertical hair when pointing to the target. If the target appears just above the central cross on FL it should appear just below the central cross on FR. This will minimize the effect of any residual rotation of the crosshairs.

Had the BS to *A* read 350° and the FS to *C* 110°, it can be seen that 10° has been swept out from 350° to 360° and then from 360° or 0° to 110°, would sweep out a further 110°. The total angle is therefore 10° + 110° = 120° or (FS - BS) = [(110° + 360°) - 350°] = 120°.

A further examination of the protractor shows that (BS - FS) = [(25° + 360°) - 145°] = 240°, producing the external angle. It is thus the manner in which the data are reduced that determines whether or not it is the internal or external angle which is obtained.
A method of booking the data for an angle measured in this manner is shown in *Table.* This approach constitutes the standard method of measuring single angles in traversing, for instance.

Measurement by directions
The method of directions is generally used when observing a set of angles as in *Figure.* The angles are observed, commencing from *A* and noting all the readings, as the instrument moves from point to point in a clockwise manner. On completion at *D,* face is changed, and the observations repeated moving from *D* in an anticlockwise manner.
Finally, the mean directions are reduced relative to the starting direction for *PA* by applying the 'orientation correction'. For example, if the mean horizontal circle reading for *PA* is 48° 54' 36" and the known bearing for *PA* is 40° 50' 32", then the orientation correction applied to all the mean bearings is obviously -8° 04' 04''.
The observations as above, carried out on both faces of the instrument, constitute a full set. If measuring *n* sets the reading is altered by 180°/n each time.



Sight to	Face	Reading			Angle		
		d	m	s			
A	L	020	46	28	80	12	06
C	L	100	58	34			
C	R	280	58	32	80	12	08
A	R	200	46	24			
A	R	292	10	21	80	12	07
C	R	012	22	28			
C	L	192	22	23	80	12	04
A	L	112	10	19			
					Mean = 80	12	06

Station	Point	Face	H.C. Reading	Angle	Mean Horizontal Angle	Remarks
A	B	L	30° 30' 15"	95 05 10	95° 02' 35"	
	C	L	125 35 25			
	C	R	305 30 25	95 00 00		
	B	R	210 30 20			

Vertical Angle Measurement

In the measurement of horizontal angles, the concept is of a measuring index moving around a protractor. In the case of a vertical angle, the situation is reversed, and the protractor moves relative to a fixed horizontal index.

Figure (a) shows the telescope horizontal and reading 90°; changing face would result in a reading of 270°. In *Figure (b),* the vertical circle index remains horizontal whilst the protractor rotates with the telescope, as the top of the spire is observed. The vertical circle reading of 65° is the zenith angle, equivalent to a vertical angle of (90° — 65°) = +25° = *a*. This illustrates the basic concept of vertical angle measurement.

Sight to	*Face*		*Reading*		*Apply misclosure*			*Mean of FL and FR reduced to FL*		
		o	*t*	*tt*	*o*	*t*	*tt*	*o*	*t*	*tt*
A	*L*	*20*	*26*	*36*	*20*	*26*	*36*	*20*	*26*	*31*
B	*L*	*65*	*37*	*24*	*65*	*37*	*22*	*65*	*37*	*18*
C	*L*	*102*	*45*	*56*	*102*	*45*	*52*	*102*	*45*	*54*
D	*L*	*135*	*12*	*22*	*135*	*12*	*16*	*135*	*12*	*16*
A	*L*	*20*	*26*	*44*	*20*	*26*	*36*	*20*	*26*	*31*
Misclosure				*+8*			*0*			
A	*R*	*200*	*26*	*26*	*200*	*26*	*26*			
D	*R*	*315*	*12*	*14*	*315*	*12*	*15*			
C	*R*	*282*	*45*	*44*	*282*	*45*	*46*			
B	*R*	*245*	*37*	*12*	*245*	*37*	*15*			
A	*R*	*200*	*26*	*22*	*200*	*26*	*26*			
Misclosure				*—4*			*0*			

Station	Point	Face	V.C. Reading	Vertical Angle	Mean Vertical Angle	Remarks
A	B	L	85° 30′ 30″	04 30 30	04° 30′ 25″	
	B	R	274 30 20	04 30 20		

Setting out circular curve using offsets from the tangent length method

Objectives

Is to set out 10m circular curve with 30 deflection angle using offsets from the tangent length method

Instruments Required

1. Two measuring tapes
2. Pegs, nails or similar
3. Methodology
4. Compute tangent length Lc
5. Select suitable range (0.5m)
6. Calculate offsets values Yi and tabulate results
7. Set out tangent points T, U and intersection point I
8. Starting from one tangent point set out values of Xi
9. Using the other tape set out values of Ys analogue to Xs
10. Repeat steps (e) and (f) above for other tangent.

Computation and Results

Tangent Length = R tan (Θ/2) = 10 tan (30˚/2) = 2.68m

$$Y = \frac{X^2}{2R}$$

X(m)	0.5	1.0	1.5	2.0	2.5
Y(m)	0.01	0.50	0.11	0.20	0.31

Setting out circular curve using offsets from long chord method

Objectives

Is to set out 10m circular curve with 30 deflection angle using offsets from long chord method

Instruments Required

1. Two measuring tapes
2. Pegs, nails or similar

Methodology

3. Compute long chord TU.
4. Select suitable range X_i (0.5m)
5. Calculate offsets values Y_i and tabulate results
6. Set out tangent points T and U
7. Set out mid-point of the long chord X_0
8. Starting from the mid-point of the long chord measure Y_0 at right angle to X_0 to set out first point on the curve.
9. From the mid-point of the long chord measure X_i towards T using one tape and measure Y_i at right angle to X_i using the other tape.
10. Repeat steps (f) and (g) above towards U to set out the second half of the curve.

Computation and Results

$\textbf{Long Chord (TU)} = 2R\sin\left(\frac{\theta}{2}\right)$=2×10×sin(30 /2)=5.18m

TU/2 = 5.18/2 =2.59 m

$$Y = \sqrt{R^2 - X^2} - \sqrt{R^2 - \left(\frac{Long\ chord}{2}\right)^2}$$

X(m)	0.0	0.5	1.0	1.5	2.0	2.5
Y(m)	0.34	0.33	0.29	0.23	0.14	0.02

Experiments described as per Al-Baha University Curriculum for Traffic and transportation laboratory.

SOIL TESTS

STANDARD AND MODIFIED PROCTOR COMPACTION TESTS

AASHTO T-99 or ASTM D698 and
AASHTO T-180 or ASTM D1557

Introduction

Testing procedures for the standard and modified Proctor test procedures are the AASHTO T99 and T180 respectively. The corresponding ASTM testing procedures are D 698 and D 1557 respectively. The differences between AASHTO T99 and T180 are shown in Table 1.

Table 1. Differences Between AASHTO T99 and T180

	AASHTO T99 (Standard Proctor)	AASHTO T180 (Modified Proctor)
Hammer Weight	5.5 lbf	10 lbf
Drop Distance	12 inches	18 inches
Energy	12,400 ft-lbf/ft^3	56,000 ft-lbf/ft^3
Number of Layers	3	5

Objectives:

The general objectives of lab compaction is to determine the proper amount of mixing water to use when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at this optimum water.

For the same soil, the optimum moisture content (OMC) for a modified Proctor test is usually less than OMC for a standard Proctor test while maximum dry density is higher.

Summary of the methods:

Standard Proctor Testing

For each soil type, water was added to the soil to bring it to a predetermined moisture content percentage. Three layers of the soils then were compacted in a standard four-inch mold using an automatic standard Proctor hammer in accordance with AASHTO T99 (ASHTO D 698). The T99 procedure specifies a hammer weighing 5.5 pounds and a drop distance of 12 inches, which creates 12,400 ft-lbf/ft³ of force.

Modified Proctor

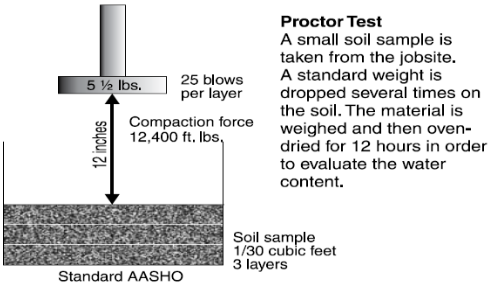
The modified proctor is similar to the standard proctor; water was added to each soil sample to bring it to the desired moisture content. Five layers of the soil then were compacted in a standard four-inch mold using an automatic modified Proctor hammer in accordance to AASHTO T180 (ASTM D 1557). The T180 procedure specifies a hammer weighing 10 pounds and a drop distance of 18 inches, which creates 56,000 ft-lbf/ft³ of force. The heavier hammer and lengthened drop distance significantly increase the compactive effort.

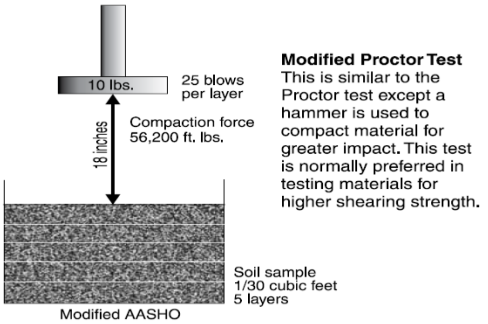
Specific Gravity

A small sample for each of the soils was taken to perform AASHTO T84 (ASTM C 128) procedures. Once the specific gravity was determined, it was used to plot a zero air voids (ZAV) curve as a reference for each soil's two compaction curves.

Equipment (see next figure)

1. Proctor mold with a detachable collar assembly and base plate.
2. Manual/automatic rammer
3. Sample Extruder.
4. A sensitive balance.
5. Straight edge.
6. Squeeze bottle
7. Mixing tools such as mixing pan, spoon, trowel, spatula etc.
8. Moisture cans.
9. Drying Oven





Test procedure

1. Obtain approximately 10 lb (4.5 kg) of air-dried soil in the mixing pan, break all the lumps so that it passes No. 4 sieve.
2. Add an approximate amount of water to increase the moisture content by about **5**%.
3. Determine the weight of empty proctor mould without the base plate and the ollar. W1, (lb). (Row #1 of the table)
4. Fix the collar and base plate.
5. Place the first portion of the soil in the Proctor mould as explained in the class and compact the layer applying 25 blows.
6. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. Place the second layer, apply 25 blows, place the last portion and apply 25 blows.
7. The final layer should ensure that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
8. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil leveling to the mould.
9. Determine the weight of the mould with the moist soil W2, (lb). Extrude the sample and break it to collect the sample for water content determination preferably from the middle of the specimen.

10. Weigh an empty moisture can, W3, (g) and weigh again with the moist soil obtained from the extruded sample in step9, W4, (g). Keep this can in the oven for water content determination.
11. Break the rest of the compacted soil with hand (visually ensure that it passes US Sieve No.4). Add more water to increase the moisture content by 2%.
12. Repeat steps 4 to 11. During this process the weight W2 increases for some time with the increase in moisture and drops suddenly. Take two moisture increments after the weights starts reducing. Obtain at least 4 points to plot the dry unit weight, moisture content variation.
13. After 24 hrs recover the sample in the oven and determine the weight W5, (g).
14. Fill out the following table completely; Calculate rows 9 and 10, these two will give one point of the plot.

Notice that; The modified compaction procedure is similar to the above with a change in the compactive effort. The rammer used in the modified compaction is a **10 lb** with a height of drop of **18"**.

Calculations and reporting the results

See Table 2

Table2: The form for compaction test					
Test No.	1	2	3	4	5
1. Weight of the mold without the base and collar, W1, (lb)					
2. Weight of the mold + moist soil, W2 (lb)					
3. Weight of the moist soil, W2-W1, (lb)					
4. Moist unit weight, γ = [(W2-W1)/(1/30)], (lb/ft3)					
5. Moisture can number					
6. Weight of moisture can, W3, (g)					
7. Mass of can + moist soil, W4, (g)					
8. Mass of can + dry soil, W5, (g)					
9. Moisture content: w(%)= [(W4-W5)/(W5-W3)] x 100					
10. Dry unit weight of compaction: γd (lb/ft3) = γt /[1+(w/100)]					

CALIFORNIA BEARING RATIO TEST (CBR)

(AASHTO T-193 or ASTM D1883).

Objective:

The California Bearing Ratio (CBR) test is used to evaluate the quality of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens.

Apparatus and Equipment

CBR test requires the following equipment:

- 152 mm diam. x 178 mm height (6*7 in) CBR compaction mold with collar and spacer disk (151-mm diam. x 61.4 mm height) (or 51mm height as available).
- Compaction rammer, either 24.4 N (5.5 lb) dropped from 305 mm (12 in) height or 44.5 N (10.0 lb) dropped from 457 mm (18 in) height as designated by instructor. (Figure 1)
- Expansion-measuring apparatus consisting of perforated plate with adjustable stem, tripod, and dial gauge reading to 0.01 mm.
- Surcharge weights as required.
- Compression machine equipped with CBR penetration piston (49.53 mm diam. with cross- sectional area of 19.35 cm^2) and capable of a penetration rate of 1.3 mm/min (0.05 in/min) (Figure 1)
- 150mm diameter course filter paper

Sample Preparation:

1- Prepare 36 kg (enough for three samples) of an air dried soil sample that passes the 19mm (3/4”) sieve. If the sample contains material larger than 19 mm it has to be replaced by an equivalent quantity passing sieve # 19 mm and retained on sieve number 4.

2- Oven dry about 200 g of the soil and determine the natural moisture content.

3- Add the required amount of water so that the moisture content of the sample is within $\pm$0.5% of the optimum moisture content.

4- Weight the empty mold and record its weight in the data sheet.

5- Assemble the 150 mm mold, extension collar and perforated base plate by clamping the mold fitted with the extension collar to the base plate.

6- Insert the spacer disc over the base plate and position a 150mm diameter course filter paper on top of the spacer disc.

7- Compact the sample in 3 or 5 (as specified) equal layers by 10 blows per layer using the specified hammer and height of drop.

8- Remove the extension ring and strike off excess soil with a straight edge. Left the mold and remove the base plate and the spacer disk.

9- Weight the filled mold and record it in the data sheet. Calculate the compacted soil density by dividing the soil weight by the mold volume (2305 cm^3).

10- Place filter paper on the base plate, then invert the mold and place it over the base plate. Place another filter paper on top of the soil in the mold.

11- Repeat steps 4 to 11 above but using 25 tamps and 65 tamps.

Figure 1: Required equipment for the CBR test

Test Procedure:

Soaking the Sample and Measurement of Swell

1- Place the perforated plate with the adjustable stem attached to it on the filter paper on top of the compacted soil sample.

2- Place a surcharge weight on the perforated plate to account for the weight of all the layers that will be placed on top of the subgrade. This surcharge weight should not be less than 4.5 Kg.

3- Place the mold in a water bath so that the water level is within 12.5 mm of the top of the mold. Water should be allowed to access the soil from the bottom of the mold. In addition, the water levels inside and outside the mold should be equal.

4- Place the tripod with the dial gauge on the mold and take the initial dial readings.

5- Allow the specimen to soak for 4 days and maintain the constant water level inside and outside the mold.

6- Periodically take the swell readings and record them in the data sheet. At the end of the soaking period, take a final dial reading and calculate the swell as a percentage of the height of the specimen (125 mm).

$$Swell\,(\%) = \frac{Amount\,of\ Swell}{Original\,Specimen\,height\,(125mm)} \times 100$$

7- Remove the expansion apparatus and surcharge weights and lift the mold out of the water bath. Allow the mold to drain for 15minutes.

8- Weigh the specimen ($W_{wet\ filled}$) and determine the soil density after soaking.

Application of Penetration Load

9- Place one 2.47Kg annular surcharge disc on the soil surface and place the mold in the loading frame.

10- Seat the penetration piston with a 4.54Kg (0.05kN) load and set the dial gauges for load and strain to zero.

11- Place further surcharge weights on the sample (if needed) until this surcharge weight equals the soaking surcharge weight.

12- Apply the load to the piston at a uniform rate of 1.27mm per minute of penetration. Note the load readings for every 0.25mm of penetration until 7.5mm of penetration.

13- On completion of the penetration release the load and remove the mold from the testing machine.

14- Remove the specimen from the mold and determine the moisture content for the entire depth of the sample.

Calculation

1- Convert loads applied to stress by dividing the load by the area of the piston. Then plot the stress against the penetration readings and draw a smooth curve through the points.

2- The curve is normally concave downward, although the initial portion might concave upward due to surface irregularity. In this case, correction should be done by drawing a tangent to the curve at the point of greatest slope. The corrected curve will be used in all further calculations. Figure 2 shows examples of corrected CBR curves.

3- From the obtained curve make a computation of the stress at the corrected penetration of 2.5mm and 5.0mm. The obtained values (in kg/cm2) are expressed as percentages of the standard stress of 1000 psi and 1500 psi respectively.

4- Calculate CBR as follows:

$$CBR\,(\%) = \frac{\text{Stress on soil at penertation of 0.1 inch (2.5 mm) in specific units}}{\text{Standard stress in the same units}} \times 100$$

The standard stress at different units are shown in the next table.

	PSI	MPa	Kg/cm^2
Standard stress at 0.1 inch (2.5 mm) penetration	1000	6.9	69
Standard stress at 0.2 inch (5 mm) penetration	1500	10.5	105

Applying standard stresses shown in the table in case of using PSI unit, the expression well be as follow:

$$CBR\,(\%) = \frac{\text{Stress on soil at penertation of 0.1 inch}}{1000} \times 100$$

If stress used was in kg/cm^2 the expression will be as follow:

$$CBR\,(\%) = \frac{\text{Stress at 2.5mm penetration (kg/cm}^2\text{)}}{69} \times 100$$

$$CBR\,(\%) = \frac{\text{Stress at 5.0mm penetration (kg/cm}^2\text{)}}{105} \times 100$$

5- Usually, the value at 2.5mm is greater than that at 5.0mm penetration and the former is taken as the CBR value.

6- If $CBR_{2.5} < CBR_{5.0}$ repeat the test on another soil sample. In the case that the second test still gives $CBR_{2.5} < CBR_{5.0}$, then take the CBR value as the value corresponding to 5.0mm penetration.

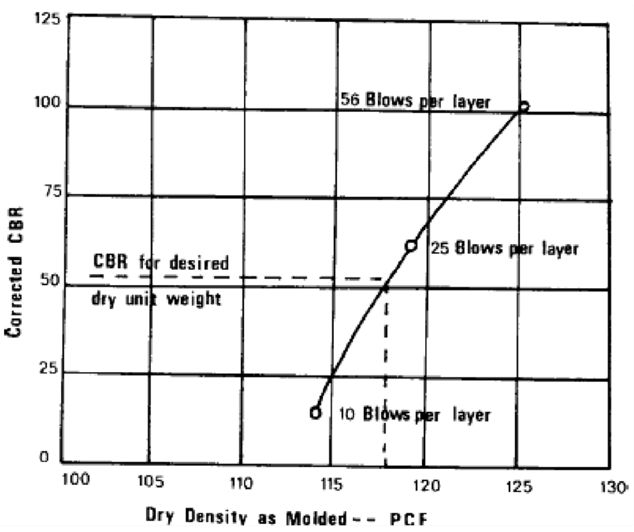


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Figure 3 Dry density versus corrected CBR values.

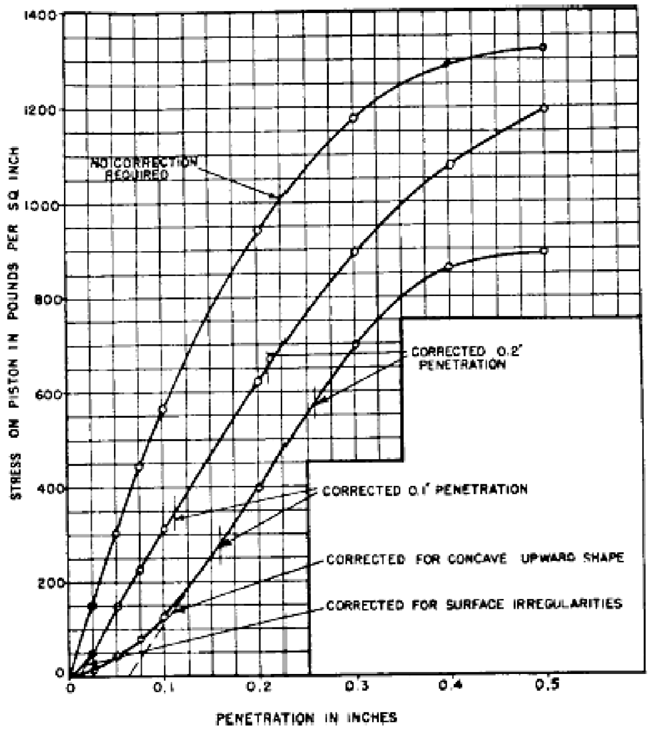


Figure 2 Corrected CBR curves.

AGGREGATE TESTS

SPECIFIC GRAVITY OF COARSE AGGREGATE

AASHTO T 85 and ASTM C 127

Objective:

The objective of the test is to find the bulk and apparent specific gravity of aggregate along with percent of absorption.

Definition:

Specific gravity of an aggregate is the ratio of the weight of a unit volume of the material to the weight of an equal volume of water at approximately 23°C (73.4°F). The commonly used equation for specific gravity is:

Specific gravity = (weight / volume) / unit weight of water

When working in the metric system the unit weight of water is 1.0 gram/ml. Hence the equation for specific gravity becomes:

Specific gravity = weight/volume

where the weight is in grams and the volume is in ml.

Significance of the Test:

Specific gravity of aggregate is useful in:

1. Making weight-volume conversions.
2. Calculating the void content in a compacted HMA.

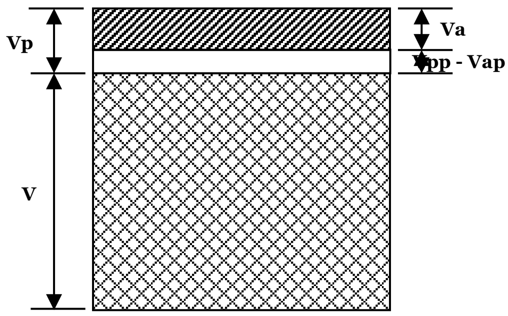
Scope:

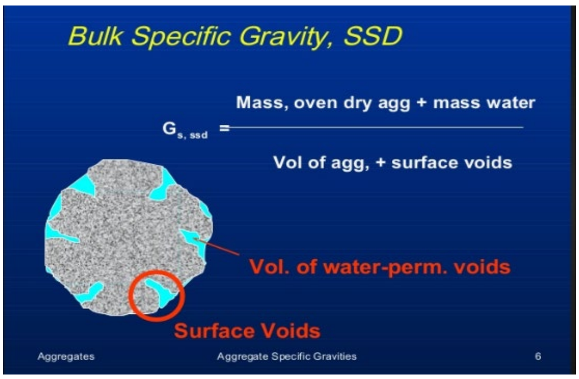
Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Water, at a temperature of 73.4°F (23°C) has a specific gravity of 1. Specific Gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used during production to separate the deleterious particles from the good using a heavy media liquid.

Specific gravity is critical information for the Hot Mix Asphalt Design Engineer. The value is used in calculating air voids, voids in mineral aggregate (VMA), and voids filled by asphalt (VFA). All are critical to a well performing and durable asphalt mix. Water absorption can also be an indicator of asphalt absorption. A highly absorptive aggregate may lead to a low durability asphalt mix.

A summary of the test procedure is:

- Approximately 5 kg of thoroughly washed aggregate retained on a No.4 (4.75 mm) sieve is oven dried to a constant weight.
- The dried sample is then immersed in water for 24 hours.
- The aggregate is removed from the water, drained, and surface dried until all visible films of water are removed. The surfaces will still appear damp.
- The weight of the sample in the surface dry condition is then obtained and recorded as **B**.
- The saturated surface dry sample is placed in a wire basket, submerged in water, and the submerged weight determined and recorded as **C**.
- The sample is then removed from the Water, drained and placed in an Oven and dried to a constant weight.
- The oven dried weight is recorded as **A**.
- Use the pervious equations to calculate the different specific gravity of aggregate.





Ws = Oven-dry weight of solids
γ_w= Unit weight of water = 1gm/cm^3
Vs = Volume of solids
Vpp = Volume of water permeable pores
Vap = Volume of pores absorbing asphalt
V pp - Vap = Volume of water permeable pores not absorbing asphalt
Apparent specific gravity = Gsa = Ws / (Vs * γ_w)
Bulk specific gravity = Gsb = Ws / ((Vs + Vpp) * γ_w) =
Effective specific gravity = Gse = Ws / ((Vs + Vpp - Vap) * γ_w) =

Relationship between the Different Specific Gravities of an Aggregate Particle

Apparatus (See Figure 1):

- Balance, conforming with class G5 (AASHTO M231)

- **The Specific** Gravity **Bench with** 2in (51mm) diameter holes in the top balance platform
- Sample container, wire basket of No. 6 (3.35 mm) or less mesh wire cloth, with a capacity of 1 to 1 3/4 gal. (4 to 7 L) to contain aggregate with a nominal maximum size of 1 1/2 in. (37.5 mm) or smaller; larger basket for larger aggregates.
- Water tank, watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water at a constant level.
- Suspended Apparatus, wire used to suspend apparatus with the smallest practical diameter. A hitest fishing leader or other thin wire with utility hook can be used with a small hook attached to the handle of the basket or sample container.
- Sieves, No. 4 (4.75 mm) or other size as needed, conforming to AASHTO M 92.

Procedure:

1. Thoroughly mix the sample and reduce the sample to the required size (Figure 2) in accordance with AASHTO T248 (Reducing Field Samples of Aggregate to Test Size). Use sample sizes as indicated in Table 1.

Table 1	
Nominal Maximum size	Min. sample weight
1/2 in. (12.5 mm)	4.4 lb (2 kg)
3/4 in. (19 mm)	6.6 lb (3 kg)
1 in. (25 mm)	8.8 lb (4 kg)
1 1/2 in. (37.5 mm)	11 lb (5 kg)
2 in. (50 mm)	18 lb (8 kg)
2 1/2 in. (63 mm)	26 lb (12 kg)
3 in. (75 mm)	40 lb (18 kg)
1/2 in. (12.5 mm)	4.4 lb (2 kg)

2. Dry sieve the sample through a No. 4 (4.75 mm) sieve and discard any material that passes the sieve (if a substantial amount of material passes the No. 4 (4.75mm) sieve, you may need to use a No. 8 (1.18 mm) sieve instead of the No. 4 (4.75 mm), or you may need to perform a specific gravity on the minus No. 4 (4.75 mm) material). Wash the aggregate retained on the No. 4 (4.75 mm) sieve.
3. Dry test sample to constant weight in an oven regulated at 230 ± 9°F (110 ± 5°C). Cool sample at room temperature for 1 to 3 hr. After the cooling period, immerse the aggregate in water at room temperature for a period of 15 hr.

4. Place entire sample in a container and weigh in water maintained at 73.4 ± 3°F (23 ± 1.7°C). Shake container to release any entrapped air and weigh on minimum diameter wire suspended below scale apparatus. Ensure that the water overflow outlet is working properly to compensate for the water displaced by the sample. Record to the nearest 1.0 g or 0.1% of total weight, whichever is greater, as the weight in Water (C).
5. Remove the sample from the container and drain any excess water from the aggregate. Using an absorbent cloth (an absorbent towel usually works best), roll the aggregate until the surface water has been removed (Figure 3). Rolling up the aggregate into the towel and then shaking and rolling the aggregate from side to side is also an effective procedure in reducing the sample to an SSD (saturated, surface-dry) condition.

   An SSD condition is one in which the aggregate has no FREE water on the surface of the aggregate. If the test sample dries past the SSD condition, immerse the sample in water for 30 minutes and resume the process of surface-drying.

6. Weigh SSD sample to nearest 1.0 g or 0.1% of the total weight, whichever is greater and record this as SSD weight.
7. Dry the sample in a pan to a constant weight in an oven set at 230 ± 9°F (110 ± 5°C). Cool in air at room temperature for 1 to 3 hr, or until the aggregate can be comfortably handled. Record weight to nearest 1.0 g or 0.1%, whichever is greater, as oven dry weight.

Calculations:

Determine calculations based on appropriate formula.

A = Oven dry weight, B = SSD weight, C = Weight in water

Bulk Specific Gravity (Gsb) = A / (B-C)

Bulk SSD Specific Gravity (Gsb SSD) = B / (B-C)

Apparent Specific Gravity (Gsa) = A / (A-C)

Absorption (% Abs) = [(B-A) / A] x 100

Figure 1: The Equipment used in the test

Figure 3: Water overflow outlet

Figure 2: Reducing sample to test size

ABRASION OF AGGREGATE BY USE OF THE LOS ANGELES ABRASION TESTING MACHINE

(ASTM C131 for fine agg. & **ASTM C535** for coarse agg.)

Objective:

To evaluate the performance of aggregate against toughness and abrasion resistance.

Scope:

This test method describes the procedure used to determine the resistance of coarse aggregate to impact in a rotating cylinder containing metallic spheres. This test is also known as the Los Angeles Rattler Test.

Summary of the method:

The Los Angeles Rattler test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres (dependent upon the test sample's grading). As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, causing an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

Apparatus (Figure 1):

- Los Angeles Abrasion Machine - See AASHTO T 96 specifications.
- Sieves - Standard, 300mm (12") dia., 4.75mm (#4) and 1.70mm(#12) sieves conforming to the requirements of AASHTO M 92.
- Balance - Conforming to the requirements of AASHTO Designation M231 (Class G5 or better) with a readability and sensitivity of 1 gram and an accuracy of 1 gram or 0.1%.
- Oven - For drying samples capable of maintaining a temperature of110 ± 5 °C (230 ± 9 °F).

- Charge - Shall consist of steel spheres averaging approx. 46.8mm (127/32") in diameter and each weighing between 390 and 445g.
- The abrasive charge, depending upon the grading of the test specimen and as shown in next table.

Grading	No of spheres
A	12
B	11
C	8
D	6
E	12
F	12
G	12

Note:

Steel ball bearings 46.0mm (1 13/16") and 47.6mm (1 7/8") in diameter, weighing approximately 400 and 440geach, respectively, are readily available. The charge may consist of a mixture of these three sizes provided that the individual spheres conform to the 395 - 445g limits and that the total charge conforms to the requirements in Section1210.4.

Preparation of test specimen:

1. Wash dirty or coated aggregate and dry to constant weight. Cool the aggregate to room temperature before preparing the test specimen.
2. Select the grading from Table 1 or Table 2 most nearly representative of the aggregate furnished for the work. Separate the aggregate on the required sieve sizes.
   Prepare the test specimen using the weight of each sieve size fraction specified for the grading selected. Determine and record the weight of the prepared test specimen to the nearest 1 g.

Table 1: Fine aggregate grading ASTM C131					
Sieve size (inch)		Weight in g for each grading			
Passing	Retained on	A	B	C	D
1½	1	1250 ± 25			
1	3/4	1250 ± 25			
3/4	1/2	1250 ± 25	2500 ± 10		
1/2	3/8	1250 ± 25	2500 ± 10		
3/8	1/4			2500 ± 10	
1/4	No. 4			2500 ± 10	
No. 4	No. 8				5000 ± 10
Total Weight		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

Table 2: Coarse aggregate grading ASTM C 535				
Sieve size (inch)		Weight in g for each grading		
Passing	Retained on	E	F	G
3	2.5	2500 ± 50		
2.5	2	2500 ± 50		
2	1.5	5000 ± 50	5000 ± 50	
1.5	1		5000 ± 50	5000 ± 50
1	3/4			5000 ± 50
Total Weight		10000 ± 50	10000 ± 50	10000 ± 50

Basic Procedure:

1. Obtain the aggregate sample to be tested and reduce the sample to adequate size (Sampling).
2. Wash the sample and oven dry to a constant mass at 230ºF (110ºC).
3. After drying, sieve the material into individual size fractions, and recombine to one of four specified gradings that most nearly represents the aggregate gradation as received. Record the total sample mass (W1). The total sample mass W1 should be about 5000 g for fine aggregate and 10000 g for coarse aggregate.
4. Place the sample and the specified number of steel spheres into the drum and rotate for 500 or 1000 revolutions for fine or coarse gradation of aggregate respectively.
5. The charge required is dependent upon the grading used.
6. Discharge the material and sieve the aggregate over a sieve coarser than a 1.70-mm (No. 12) sieve.
7. Sieve the finer material on a No. 12 (1.70 mm) sieve.
8. Wash the aggregate coarser than the No. 12 (1.70 mm) sieve and oven-dry to a constant mass at 230ºF (110ºC). After cooling, determine the mass W2.
9. Calculate the percentage of loss as follow:

$$\% \text{ Loss} = [(W1-W2)/ W1]*100$$

Where:
W1 = Weight of original test specimen to the nearest 1 g
W2 = Weight retained on the No. 12 sieve after the specified number of revolutions to the nearest 1 g

Notes:

- There is no standard L.A. abrasion specification for Superpave mix design; specifications are typically established by state or local agencies.
- Typically U.S. state specifications limit the abrasion of coarse aggregate for **HMA** use to a maximum ranging from 25 to 55 percent, with most states using a specification of 40 or 45 percent.
- Requirements for Portland Cement Concrete (PCC) tend to be similar, while requirements for specialized mixes such as Stone Matrix Asphalt (SMA) tend to be lower;
- AASHTO specifies a maximum L.A. abrasion loss of 30 percent for SMA.

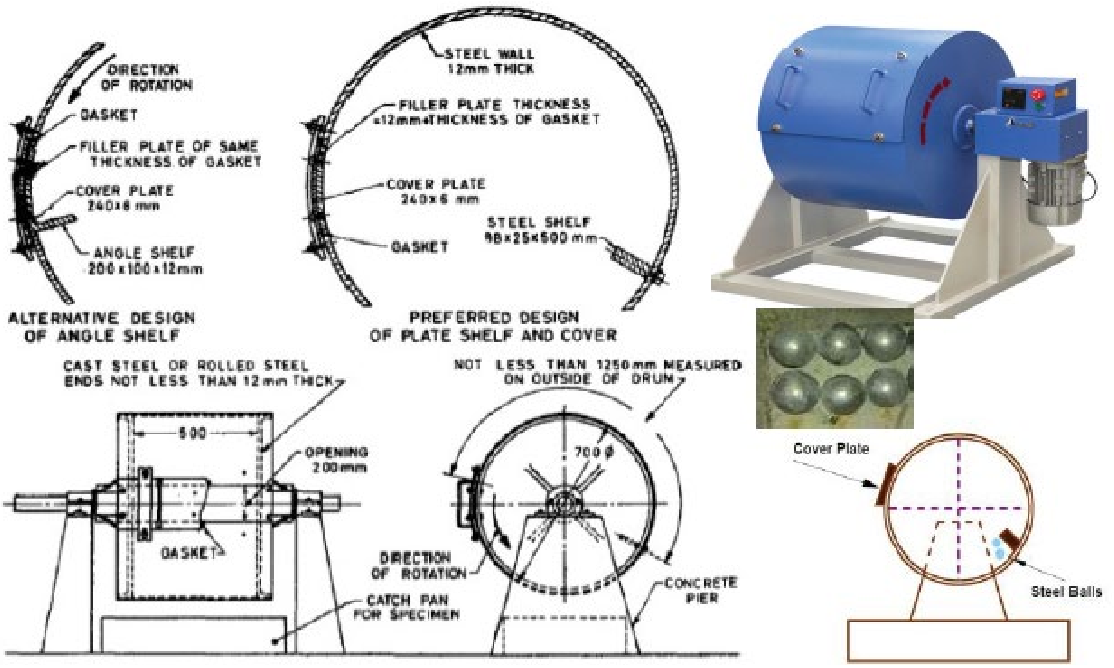


Figure 1: Los Angeles Abrasion Machine

BITUMINOUS MATERIALS TESTS

PENETRATION OF BITUMINOUS MATERIALS

ASTM D5-97

Objective:

Used to measure consistency of bituminous materials under specific conditions of loading, testing time and temperature.

Definition:

Penetration of a bituminous material is defined as the distance in tenths of millimeter that a standard needle vertically penetrates a sample of bitumen under specified conditions of load, time and temperature.

Significance of the Test:

The penetration value is a measure of the consistency of the tested bituminous material. Lower values of penetration indicate harder materials. Therefore, the result can be considered as a property of the material and can be used to describe its softness.

Apparatus and Equipment:

The required apparatus for the penetration test isshown in Figure 1. It consists of the following:

1. Penetrometer consisting of a needle holder which is connected to a scale capable of measurements to the nearest 0.1 mm.
2. Weights of 50, 100 and 200 gm.
3. Standard penetration needle.
4. Sample containers as follows:

	Penetration <200	200 < Penetration <350
Diameter	55 mm	35 mm
Internal Depth	55 mm	75 mm

5. A standard water bath capable of maintaining temperature of 25 ± 1 °C.
6. Transfer dish of capacity > 350 ml.
7. Stop watch accurate to ± 0.1 second.
8. Thermometer.
9. Gloves.

Sample Preparation:

1. Heat the sample with care until it is practically fluid. Note not to overheat the sample more than 60°C above the softening point.
2. Pour the sample into the container to a sufficient depth. It is a good practice to fill the container 2 to 5 mm below the tip.
3. Let the sample cool to room temperature. Cover the sample against dust. Prepare two samples (at least) for every condition of the test.
4. Transfer the samples using the transfer dish and place them in a water bath having a controlled temperature. The standard temperature is 25°C.
5. Keep the sample in the water bath for about two 1.5 to 2 hours before testing.

Test Conditions:

If the standard temperature could not be met, then special alterations should be made as follows:

Temperature (°C)	0	4	25	45
Load (gm)	200	200	100	50
Time (seconds)	60	60	5	5

Test Procedure:

1. Clean the needle and place it in its holder.
2. Place the correct weight in position above the needle.
3. Transfer the sample to be tested using the transfer dish and place it in position.
4. Lower the needle carefully until it touches the surface of the sample. You can watch the reflection of the needle at the surface of the sample. The needle should be at least 10 mm from the sides of the can.
5. Bring the pointer of the apparatus to zero position, or take the initial reading.
6. Release the needle holder quickly and simultaneously start the stopwatch.
7. Once the specified period of time is reached, record the reading of the distance the needle moved and report the value in tenths of millimeter.
8. Make at least three readings following steps 1 to 7. Make sure to satisfy the following:
    A. Each reading should be at least 10 mm far from the previous one.
    B. During cleaning of the needle, the sample must be kept in the water bath at the specified temperature.

C. If penetration is > 200 mm, the needles should be left in the sample until all the three readings have been completed.

9. Report the average of at least three readings as the penetration of the tested bituminous material.

Report:

1. Obtain the penetration of the tested material.
2. Judge the acceptability of the test results based on the following:
   a. For single operator, the coefficient of variation for penetrations above 60 should be less than 1.4%; and for penetrations below 50 the coefficient of variation should be less than 0.35%.
   b. The results of two properly conducted tests by the same operator on the same material of any penetration using the same equipment should not differ from each other by more than 4% or 1 unit whichever is larger.
   c. For multilaboratory precision, the coefficient of variation for penetrations above 60 should be less than 3.8%; and for penetrations below 50 the coefficient of variation should be less than 1.4%.
   d. The results of two properly conducted tests on the same material of any penetration, in two different laboratories should not differ from each other by more than 11% or 4 units whichever is larger.
3. Based on the penetration value, find the grade of the bitumen and comment on the suitability of the tested bitumen for use in road mixes. Refer to the following table.

Penetration	Uses
40 – 50	Bituminous mixtures known as gap-graded (hot-rolled asphalts).
60 – 70	Bituminous mixtures known as gap-graded or continuously graded mixes (asphalt concreters).
80 – 100	Continuously graded mixtures or dense bitumen macadam base stabilization, and in hot climates for surface dressing maintenance with precoated clippings in areas where high surface stress occurs.
150 – 200	Continuously graded mixtures, bitumen macadam, and surface dressing.

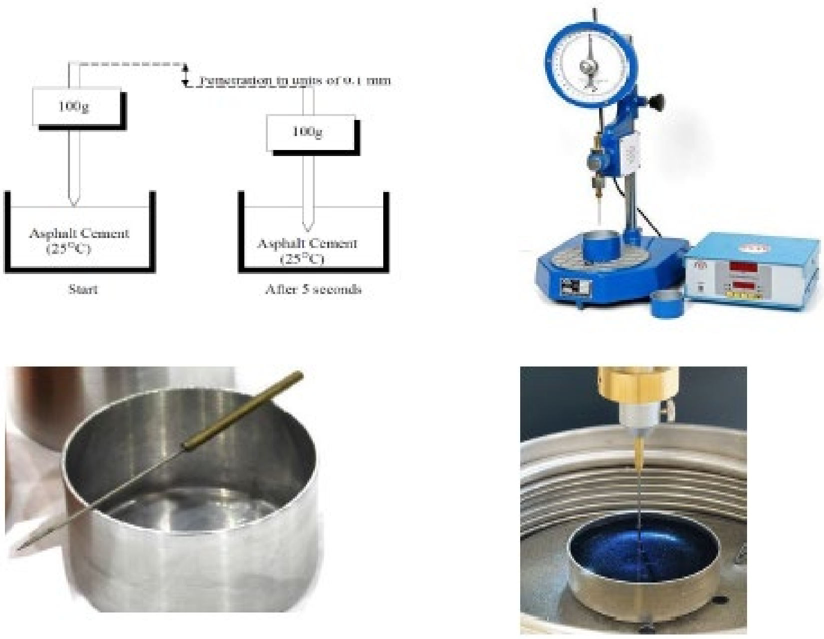


Figure 1: Asphalt penetration apparatus

SOFTENING POINT OF BITUMEN

(Ring-and-Ball Apparatus)

ASTM D36-95

Objective:

The main objective is to measure and specify the temperature at which bituminous binders begin to show fluidity. It is also a measure of consistency for air-blown asphalt.

Definition:

The softening point is practically defined as the temperature at which a disc of bitumen softens enough to allow a standard ball resting on it to move downward a distance of 25 mm.

Significance of the Test:

- Bitumens are viscoelastic materials without sharply defined melting points; they gradually become softer and less viscous as the temperature rises. For this reason, softening points must be determined by an arbitrary and closely defined method if results are to be reproducible.
- The softening point is useful in the classification of bitumens, as one element in establishing the uniformity of shipments or sources of supply and is indicative of the tendency of the material to flow at elevated temperatures encountered in service.

The results of the test might be used to:

1. Classify bitumens according to their susceptibility to heat.
2. Classify bitumens according to their suitability to use in hot or cold regions.
3. Check the uniformity of sources of supplies.
4. Indicate the tendency of bitumen to flow at elevated temperatures.

Apparatus and Equipment:

The apparatus used in this experiment is called the “Ring and Ball Apparatus”, which is shown in Figure 1. Figure 2 at the end of this experiment shows the dimensions of the apparatus parts.

The apparatus consists of the following:

1. Two brass rings.

2. Two 9.5-mm diameter steel balls, each weighs 3.5 gm.
3. Ball centering guides.
4. A flat brass plate.
5. Water bath in the form of a glass vessel.
6. Heating source.
7. Stirrer.
8. Thermometer capable of measuring temperatures in the range of 2 to 80°C., for low-softening point bitumens, or thermometer capable of measuring temperatures in the range 30 to 200°C., for high-softening point bitumens.
9. Any type of silicone oil or grease.
10. Liquid as recommended in Table 1.

Table 1. Recommended Softening Point test conditions.

Test Condition	**1**	**2**	**3**
Expected Softening Point	30 °C to 80 °C	80 °C to 160 °C	30 °C to 110 °C
Recommended Liquid	Freshly boiled distilled water	USP glycerin	Ethylene glycol
Best Thermometer	ASTM 15C or 113C	ASTM 16C or 113C	ASTM 113C
Starting Temperature	5 ± 1°C	30 ± 1°C	5 ± 1°C

Sample Preparation:

1. Heat the bitumen carefully, with frequent stirring, until it becomes sufficiently fluid to pour. The maximum allowed temperature should not exceed 110°C above its expected softening point. If the sample is a coal-tar pitch, then the maximum allowed temperature should not exceed 55 °C above its expected softening point.
2. Grease the rings and the pouring plate with a thin layer of grease or silicon oil.
3. Heat the two brass rings to the approximate pouring temperature.
4. Place the rings on the pouring plate.
5. Pour the sample in the rings allowing some excess of the material.
6. Let the specimen to cool at room temperature for half an hour. Cut the excess material with a sharp-edged knife.
7. Since the softening point is not known in advance, it is quite useful to keep the specimen in a refrigerator in order to obtain low temperature well below the expected softening point.

Test Procedure:

1. Select the suitable test condition from Table 1:
2. Assemble the apparatus into its position.
3. Fill the bath with the suitable liquid, as indicated in Table 1, making sure that the liquid depth is 105 ± 3 mm.
4. Start heating or cooling the sample carefully in order to arrive at the starting temperature. Maintain this temperature for 15 minutes with the apparatus in place.
5. Place the ball in the center of the sample using the ball-centering guide.
6. Start heating and observing temperature. Make sure that heating is at the rate of 5°C per minute.
7. Record the temperature at which the bitumen surrounds each ball touches the support plate (i.e. moved a distance of 25 mm).

Calculations:

1. Obtain the softening point as the average of the two samples. Report the value to the nearest 0.2°C when ASTM Thermometer 15C is used. Report the value to the nearest 0.5°C when ASTM Thermometer 15C or 113C is used.
2. If water was not the liquid (as in condition 1) and the result was > 80°C, adjust the values as follows:
    a. If condition 2 was used, then the correction factor should be –4.2°C, if the tested material is asphalt.
    b. If condition 2 was used, then the correction factor should be –1.7°C, if the tested material is coal-tar pitch.
    c. If condition 3 was used, then the results must be adjusted as follows:
        1) SP (glycerin) = 1.027 x SP (Ethylene glycol) – 1.35°C, if the material tested is *asphalt*.
        2) SP (water) = 0.974 x SP (Ethylene glycol) – 1.44°C, if the tested material is *asphal*t.
        3) SP (glycerin) = 1.045 x SP (Ethylene glycol) – 5.06°C, if the tested material is *coal-tar pitch*.
        4) SP (glycerin) = 1.061 x SP (Ethylene glycol) – 8.41°C, if the tested material is *coal-tar pitch*.
3. Obtain the standard deviation of all the tested samples.

Comments:

1. If the difference between the two samples in the same test exceeds 1°C, the test must be repeated.
2. The difference between the results of two properly conducted tests by the same operator should not exceed 1.2°C (i.e. the standard deviation ≤0.41°C) when *conditions 1 or 2* are applied.
3. The difference between the results of two properly conducted tests from different laboratories should not exceed 2°C (i.e. the standard deviation ≤0.70°C) when *conditions 1 or 2* are applied.
4. The difference between the results of two properly conducted tests by the same operator should not exceed 2°C (i.e. the standard deviation ≤0.72°C) when *condition 3* is applied.
5. The difference between the results of two properly conducted tests from different laboratories should not exceed 3°C (i.e. the standard deviation ≤1.08°C) when *condition 3* is applied.

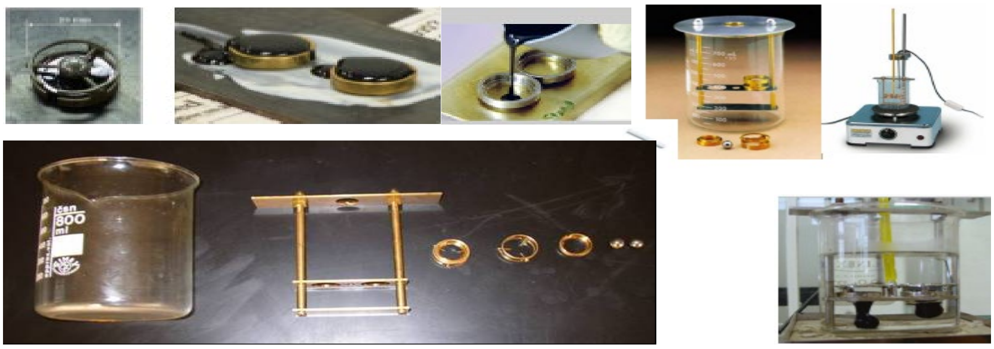


Figure 1: Ring & Ball Apparatus

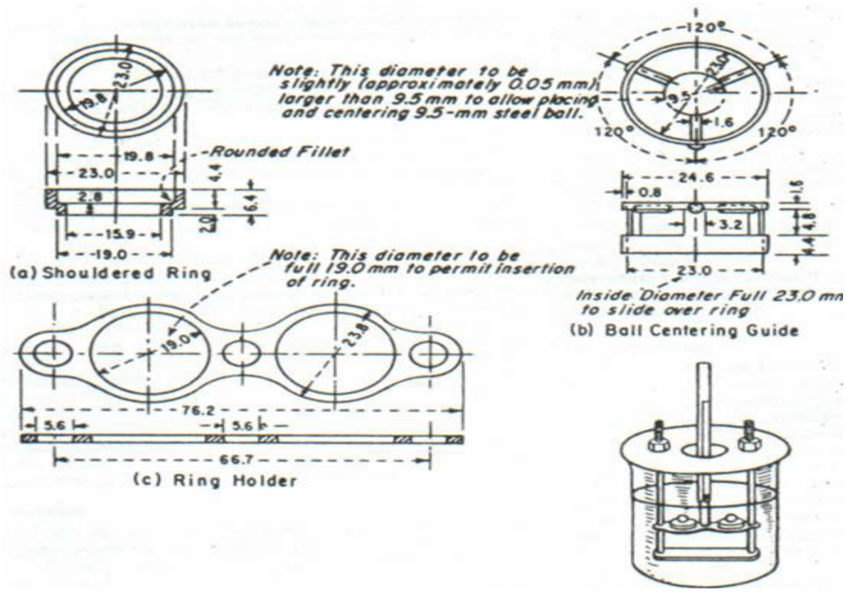


Figure 1: Compaction pedestal and compaction hammer

SAYBOLT VISCOSITY OF LIQUID ASPHALT

(UNIVERSAL and FUROL)

AASHTO T-72 or ASTM D88-81

Objective:

To determining saybolt viscosity of petroleum products at specified temperature.

Definitions:

Saybolt Universal viscosity is defined as the efflux time, in seconds, for a standard sample, 60 ml, to pass through a standard, Universal, orifice under specified conditions.

Saybolt Furol viscosity is defined as the efflux time, in seconds, for a standard sample, 60 ml, to pass through a standard, Furol, orifice under specified conditions. The relationship between Saybolt and Universal viscosities is as follows:

Saybolt Universal viscosity = 10 x Saybolt Furol viscosity **(1)**

Furol (according to ASTM) is an acronym of "**F**uel and **r**oad **oi**ls"

Significance of the Test:

The test can be used to:

1. Characterize certain petroleum products and compare their uniformity.
2. Obtain an indirect measure of the consistency of petroleum product.
3. Judge and compare the uniformity of shipments and supplies.
4. The results can be used to obtain an estimate of the kinematic viscosity using special tables.

Apparatus and Equipment: (See Figure 1):

1. Thermometers capable of measuring temperatures up to 0.2 °C.
2. Filter funnel with interchangeable 150-µm and 75-µm wire-cloth inserts.
3. Receiving flask having a volume greater than 60 ml with a calibration mark at the 60 ml volume.
4. Timer with accuracy of 0.1 of a second.

Sample Preparation:

Heat the sample with care stirring occasionally. Make sure that the sample temperature does not exceed the flash point minus 28°C.

Test Procedure:

1. Choose the suitable orifice. Use the Universal orifice with liquids and cutbacks having low viscosity. Use the Furol orifice with liquids and cutbacks having high viscosity.

2. Clean the viscometer and all other equipment with a solvent and then dry them completely.
3. Place the receiving flask in position, centered beneath the orifice.
4. Fill the bath with the suitable liquid to a level 6 mm above the overflow of the rim of the viscometer.
5. Stir the sample during heating so that the sample temperature is as close as possible to the temperature of the bath.
6. Calibrate the Saybolt viscometer using standard oil at temperature of 37.8°C following the same steps as for testing the sample.
7. Calibrate the Furol viscometer using standard oil at temperature of 50°C following the same steps as for testing the sample.
8. Choose the test temperature using the following table:

Viscosity	Standard Test Temperature: °C (°F)
Universal	21.1 (70), 37.8 (100), 54.4 (130), 60 (140), 82.2 (180), 98.9 (210)
Furol	25 (77), 37.8 (100), 50 (122), 60 (140), 82.2 (180), 98.9 (210)

9. After choosing the test temperature, control the temperature of the bath to the required one.
10. Close the sample outlet tightly using the cork stopper.
11. Stir the sample and then strain it through the 150-µm-wire cloth in the filter funnel directly into the viscometer until the levels are above the flowing rim.
12. Immerse the thermometer in the sample in its position in the viscometer and stir well. Withdraw the thermometer.
13. Check the sample temperature while stirring. The temperature must be within 0.03°C of the test temperature. Stirring in a circular motion should continue until the required temperature is reached.
14. Snap the cork stopper from the outlet and start the timer simultaneously.
15. Stop the timer once the level of the oil reaches the calibration mark.

Calculations:

Calculate the Saybolt viscosity at the specified temperature as follows:

Saybolt viscosity (Universal or Furol) at temperature (T) =
Time x Correction Factor (2)

Correction factor = Standard time / Measured time during calibration (3)

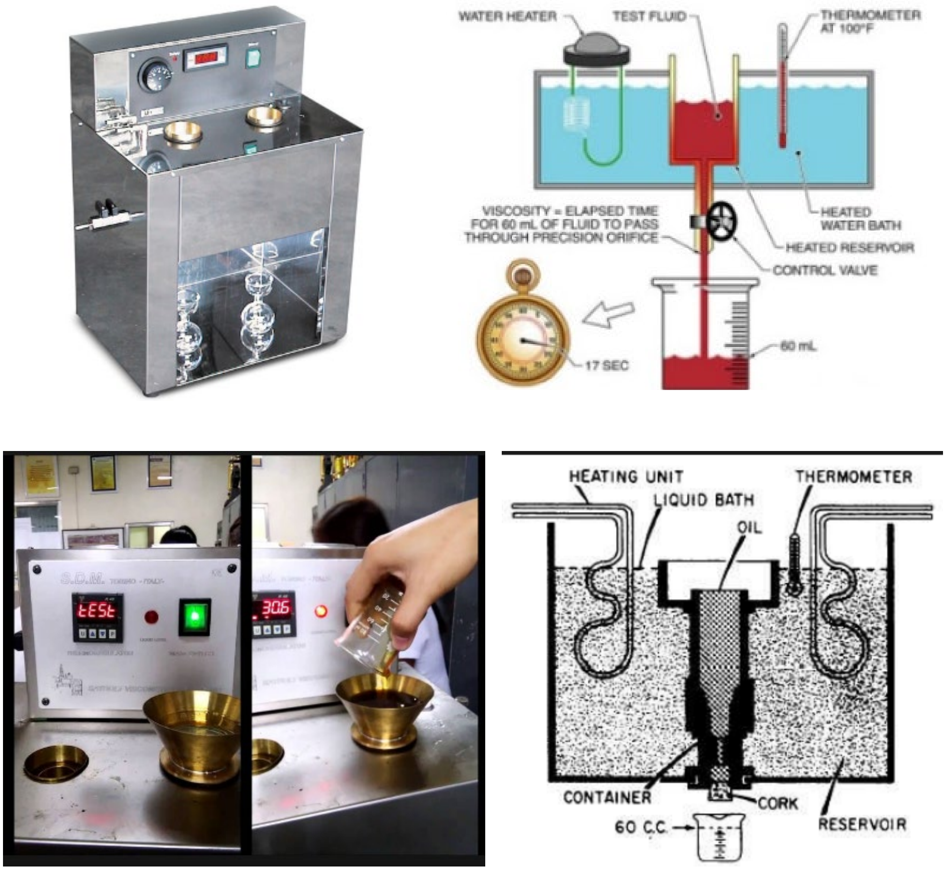


Figure1: Saybolt viscometer and bath

ASPHALT MIXES TESTS
(Marshall method)

MARSHALL MIX DESIGN PROCEDUR

ASTM D6926 -16 +
ASTM D 2726 +
AASHTO T-245 or ASTM D5581 +
AASHTO T-209 or ASTM D2041

Objective:

The objective of Marshall Mix Design procedure is to find the optimum binder content in the mix.

The Marshall mix design procedure consist of three parts as follow:

Part 1: Sample preparation ASTM D6926 -16

Part 2: Sample testing which include

A. Bulk Specific Gravity Determination Gmb. ASTM D 2726
B. Stability and flow test for compacted asphalt mixture. AASHTO T-245 or ASTM D5581
C. Maximum specific gravity test for loss asphalt mixture. AASHTO T-209 or ASTM D2041
D. Density & voids analysis.

Part 3: Report and discussion

Part 1: Sample Preparation.

Introduction:

In this experiment, students will prepare different asphalt concrete mixes by varying the asphalt content in each mix in accordance with the Marshall method of mix design. These specimens will be tested to obtain the optimum asphalt content by performing the Marshall test for stability and flow, bulk specific gravity and unit weight, theoretical maximum specific gravity and air voids percentage in total mix.

Material and Equipment:

1. Asphalt, course aggregate, fine aggregate, and mineral filler.
2. Sieve analysis equipment.
3. Pans and mixing molds.
4. Spatula; balance; oven & hot plate.
5. Mixing bowl and mixer.

Preparation Procedure:

a) The aggregates to be used are dried to constant weight and sieved into the following size fractions: 1" (passing), 3/4", 1/2", 3/8", #4, #8, #30, #50, #100, #200.

b) Blend sufficient aggregate to produce three, 2.5" height, specimens at each asphalt content. Usually five different asphalt contents are used in the mix design. Around 1150 gm of aggregate are sufficient to produce one Marshall Sample. Additional three samples are required for the determination of theoretical maximum specific gravity. A minimum of 2000 gm per sample are required for theoretical maximum specific gravity samples.

Blending of the aggregate should be according to the road type and layer position (either wearing or binder course). In this experiment we will make the mix design for a heavy trafficked wearing course layer. Therefore, the blending of the aggregates should be according to the following proportions:

Sieve Size	% Passing
1"	100
3/4"	95
1/2"	80.5
3/8"	68
#4	45.5
#8	30.5
#16	23
#50	11
#100	8.5
#200	5

c) Determine the ranges of mixing and compaction temperatures from the temperature-viscosity plot:

- Mixing temperature should be selected to provide a viscosity of 170 ± 20 centistokes.
- Compaction temperature should be selected to provide a viscosity of 280 ± 30 centistokes.

d) Heat enough asphalt, at the obtained mixing temperature, to prepare a total of 18 specimens. Three specimens should be prepared at each of the selected five different asphalt contents. Asphalt contents should be selected at 0.5 percent increments with at least two asphalt contents above "optimum" and at least two below "optimum".

Additional three loose mixture specimens should be prepared near the optimum asphalt content for determining theoretical maximum specific gravity.

e) Heat the aggregate to a temperature 10°C above the mixing temperature (from c above).

f) Place the aggregate in the mixing bowl and add the required amount of the asphalt cement and mix the aggregate and asphalt quickly and thoroughly. As stated above, five different asphalt cement percentages by weight of the mix are proposed:

Asphalt Cement Percent by weight of mix	No. of Specimens	Weight of Asphalt to be Added per Sample
4.0	3	48.0
4.5	3	54.3
5.0	3	60.6
6.0	3	67.0
6.5	3	73.5

g) Clean and heat the molds and hammer to be between 100 and 150°C. Place a piece of filter paper in the bottom of the mold.

h) Place half of the required amount of the mix in the mold and spade the mixture vigorously with a heated spatula 15 times around the perimeter and 10 times over the interior. Place the second half of the batch in the mold and repeat the foregoing procedure. Remove the collar and smooth the surface of the mix with a trowel to a slightly rounded shape. Place a piece of filter paper.

i) Replace the collar and place the mold assembly on the compaction pedestal. (Figure 1 photo A) Apply 75 blows of the 10 Ib hammer, falling freely a distance of 18”. Remove the mold and turn it over and apply the same number of blows to the other side.

j) Remove the two filter papers and leave the sample to cool down then extrude the sample.

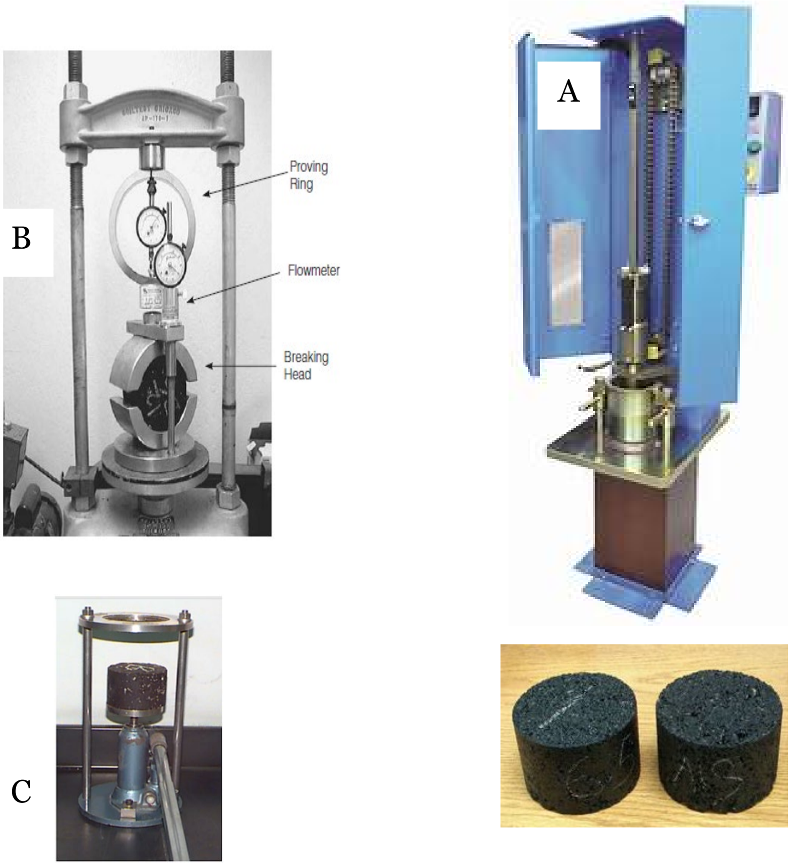


Figure 1: Marshall Mix Design:
Samples and equipment

Part 2 – Sample testing

Introduction:

In this part, the following tests and analysis will be carried out (on the samples prepared in Part I) of this experiment:

A. Bulk specific gravity determination (ASTM D 2726).

B. Stability and flow test.

C. Theoretical maximum specific gravity determination (ASTM D 2041).

D. Density & voids analysis.

Apparatus and Equipment

a) Marshall testing machine with sample holding mould (Figure 1- photo B).

b) Water bath for heating the Marshall samples.

c) Balance with specific gravity frame.

d) Large size pycnometer with vibrator.

e) Vacuum pump.

A. Bulk Specific Gravity Determination:

This test is performed according to ASTM D 2726 test procedure as follows:

(a) Measure the height or thickness of the specimen and take its weight in air. Designate this as **A**.

(b) Immerse the specimen in a water bath at 25°C for 3 min to 5 min and then weigh in water. Designate this weight as **C**.

(c) Surface dry the specimen by blotting quickly with a towel and then weigh in air. Designate this weight as **B**.

(d) Record the weights A, B & C for each sample in Worksheet # 1. Calculate the Bulk specific gravity of the compacted specimens as follows:

$$\boxed{\text{Bulk specific gravity} = A/(B - C)} \qquad (1)$$

where, A = mass of the dry specimen in air, g,

B = mass of the saturated surface-dry specimen in air, g, and

C = mass of the specimen in water, g.

B. Stability & Flow Test:

(a) Immerse the specimen in the water bath at 60°C ± 1°C for 30-40 minutes before test.

(b) Thoroughly clean the inside surfaces of the testing ring. Ensure that the dial indicator in the proving ring is securely fixed and is zeroed for the no-load position.

(c) Remove the specimen from the water bath, dry the surfaces and place the sample in the lower half of the testing ring. Fit the upper testing head into position and center the complete assembly in the loading device.

(d) Place the flow meter over one of the guide rods and initialize it.

(e) Apply load to the specimen, at a constant rate of deformation, 1 in. per min, until failure occurs. The *maximum* load required to produce failure, in kN at 60°C is recorded as the Marshall Stability value.

(f) The reading on the flow meter at the point of maximum load is recorded as the flow value of the specimen, expressed in mm.

Note: The entire procedure from removal from the water bath to failure of the specimen should not take longer than 30 secs.

(g) Data obtained should be recorded in Worksheet # 1.

C. Theoretical Maximum Specific Gravity:

Determine the theoretical maximum specific gravity by ASTM method D2041. The test is performed on the loose mixed sample prepared in Part I of this experiment.

a- Separate the particles of the sample, taking care not to fracture the mineral particles, cool the sample to room temperature, place in a container and get the net weight of the sample. Designate the net weight of the sample as **A**.

b- Fill the large-size pycnometer (*Type E*) with water. Put the transparent cover in place and fill the pycnometer with water till it gets completely full upto the brim. Care should be taken to release any air bubbles entrapped by jarring the side of pycnometer. The outside of the pycnometer is then wiped dry. The filled pycnometer is then weighed. Designate this weight as **D**.

c- Put the asphalt concrete mix sample in the pycnometer and add sufficient water at room temperature (25°C) to cover the sample.

d- Remove entrapped air by subjecting the contents to an increasing vacuum until the residual pressure manometer reads 30 mm Hg or less. Maintain this residual pressure for 5 to 15 min. While vacuuming, agitate the container and contents either continuously by mechanical device or manually by vigorous shaking at intervals of about 2 min. At the end of the interval, gradually release the vacuum.

e- For any given mix, optimum time of vacuum application or agitation may be established by trials or by experience. Lean mixes required less and rich mixes may require more time or agitation. In general, the minimum time required to dispel all the free air is 10 min.

f- Immediately after removal of entrapped air, fill the pycnometer with water and dry the outside using towel. Determine the mass of the container (and contents) and designate this weight **E**.

g- Calculate the theoretical maximum specific gravity of the sample (@ 5% AC) as follows:

$$\text{Theo. Max. Sp. Gravity (Gmm)} = A / (A + D - E) \qquad (2)$$

where, A = mass of oven dry sample in air, g,
D = mass of container filled with water at 25°C (77°F), g, and
E = mass of container filled with sample and water at 25°C, g.

D. Density & Voids analysis:

Definitions

Air voids: the pockets of air between the bitumen-coated aggregate particles in a compacted bituminous paving mixture.
Dense bituminous paving mixtures: bituminous paving mixtures in which the air voids are less than 10% after compaction.
After the completion of the stability and flow tests, bulk specific gravity, and theoretical maximum specific gravity, determine the average unit weight or density for each asphalt content by multiplying the average bulk specific gravity value by 62.4 Ib/ft^3 or 1000 kg/m^3. Then determine the % Air voids for each mix using the following formulas:

1) Based on the maximum specific gravity, Gmm, value at optimum asphalt content determined by the experiment, calculate the effective specific gravity (Gse) of aggregate. Then using Gse, find out Gmm values at the different asphalt contents with the help of the following formulas:

$$Gse = \frac{Pmm - Pb}{\frac{Pmm}{Gmm} - \frac{Pb}{Gb}} \qquad (3)$$

$$Gmm = \frac{Pmm}{\frac{Ps}{Gse} + \frac{Pb}{Gb}} \qquad (4)$$

where, Gse = effective sp. gravity of aggregate,
Gmm = maximum theoretical sp. gravity at a particular asphalt content,
Pmm = 100% (Total loose mixture),
Ps = % aggregate by total weight of mixture,
Pb = % asphalt by total weight of mixture, and
Gb = sp. gravity of asphalt.

2) The percent air voids in a compacted bituminous paving mixture is calculated as follows:

Percent air voids (AV)

$$\text{\% air voids (AV)} = \left[1 - \frac{Bulk\ Sp.Gravity}{Theoritical\ Max.Sp.Gravity}\right] * 100 \qquad (5)$$

3) Calculate Volume of asphalt and Voids Filled with asphalt at each asphalt content as follows:

$$\text{Volume of asphalt (Vb)} = \frac{\%AC \times Gmb}{Gb} \qquad (6)$$

Voids Filled with Asphalt (VFA) = [Vb / (Vb + AV)] * 100 (7)

4) Calculate Voids in Mineral Aggregate (VMA) at each asphalt content and check your calculated values of VFA from the following equations:

Voids in Mineral Aggregate (VMA) = 100 [1 - $\frac{Gmb\,(1-Pb)}{Gsb}$] (8)

Voids Filled with Asphalt (VFA) = [$\frac{VMA-AV}{VMA}$] * 100 (9)

Part 3. Report and discussion

a) Determine unit weight (density), stability & flow and % air voids for each asphalt percentage.
b) Plot unit weight versus asphalt content.
c) Plot Marshall Stability versus asphalt content.
d) Plot flow versus asphalt content.
e) Plot air voids (AV) versus asphalt content.
f) Plot voids-filled with asphalt (VFA) versus asphalt content.
g) Plot voids in mineral aggregate (VMA) versus asphalt content.
h) Determine the optimum asphalt content from air void curve, which yield **4% AV**. At the corresponding asphalt content check the following:
    i. Marshal Stability;
    ii. Flow;
    iii. Voids in Mineral Aggregate (VMA); and
    iv. Voids Filled with Asphalt (VFA).
i) Compare the corresponding values with the recommended limits from Ministry of Public Works & Housing. If corresponding values outside recommended limits, reselect optimum asphalt content and check corresponding values.
j) Determine the optimum asphalt content from curves, which yield the following:
    (1) Maximum stability.
    (2) Maximum unit weight.
    (3) Median of limits for percent air voids.

k) Compare the recommended optimum asphalt content from i & j above.

Basic Data for Sample Preparation of Paving Mixture

Worksheet # 1. Aggregate Gradation for Wearing Course Mix

Sieve Size	% Passing	% Retained	Wt. Retained	Cumulative Retained Wt.
1"	100	-	-	0
3/4"	95	5	58	58
1/2"	80.5	14.5	167	225
3/8"	68	12.5	144	369
#4	45.5	22.5	259	628
# 8	30.5	15	173	801
# 16	23	7.5	86	887
#50	11	12	138	1025
#100	8.5	2.5	29	1054
#200	5	3.5	40	1094
Pan	-	5	58	1152
		Total	1152 gm	

Worksheet # 2. Weight of Added Asphalt for each Asphalt Percentage:

Wt. Of added Asphalt (based on wt. Of total mix) = $\frac{AC\%}{1-AC\%}\times 1152$

%AC	Wt. Of Asphalt (gm)
4.0	48.0
4.5	54.3
5.0	60.6
5.5	67.0
6.0	73.5

Specific Gravity of Asphalt (Gb) == 1.022

Worksheet # 3 Marshall Stability Testing Sheet

AC, percent	Weight in air (A)	Weight in water (C)	SSD Weight (B)	Specimen Height (mm)	Bulk SP. GR. (Gmb) $\frac{A}{B-C}$	Density (Unit Wt.) Kg/mt^3	Flow (mm)	Stability (kg)
4.0								
4.5								
5.0								
5.5								
6.0								

Worksheet # 4 Theoretical Maximum Specific Gravity Testing Sheet

A.C. Percent (%)	Wt. of Mix in Air (A)	Wt. Of Pycnometer Plus Water (D)	Wt. of Pycnometer + Water + Sample (E)	Theo. Max. Specific Gravity $\frac{A}{A+D-E}$	Air Voids in Total Mix, (%) $[1-\frac{Gmb}{Gmm}]\times 100$
4,0					
4.5					
5.0					
5.5					
6.0					

Example of Hot Mix Design Specifications (as per some agencies)

Property	**Heavy Traffic**		**Medium & Light Traffic**		**Accepted Tolerance**
Sieve Size	**Binder Course**	**Wearing Course**	**Binder Course**	**Wearing Course**	
1"	100	**100**	100	100	± 5.0%
3/4"	70 – 100	**90 – 100**	70 – 100	90 – 100	± 5.0%
1/2"	53 – 90	**71 – 90**	53 – 90	71 – 90	± 5.0%
3/8"	40 – 80	**56 – 80**	40 – 80	56 – 80	± 5.0%
# 4	30 – 56	**35 – 56**	30 – 56	35 – 65	± 4.0%
# 8	23 – 38	**23 – 38**	23 – 49	23 – 49	± 4.0%
# 20	13 – 27	**13 – 27**	14 – 43	14 – 43	± 4.0%
# 50	5 – 17	**5 – 17**	5 – 19	5 – 19	± 4.0%
# 80	4 – 14	**4 – 14**	4 – 15	4 – 15	± 4.0%
# 200	2 - 8	**2 - 8**	2 - 8	2 – 8	± 1.5%
Bitumen Content					± 0.3%
Marshal Stability (kg)	900 (min)	**1000 (min)**	800 (min)	900 (min)	
Flow (mm)	2 – 3.5	2 – 3.5	2 - 4	2 – 4	
VMA	13 (min)	14 (min)	13 (min)	14 (min)	
Air Voids (%)	4 - 7	4 - 6	3 - 5	3 - 5	
Stiffness (kg/mm)	500 (min)	500 (min)	500 (min)	500 (min)	
Loss of Stability (%)	25 (max)	25 (max)	25 (max)	25 (max)	