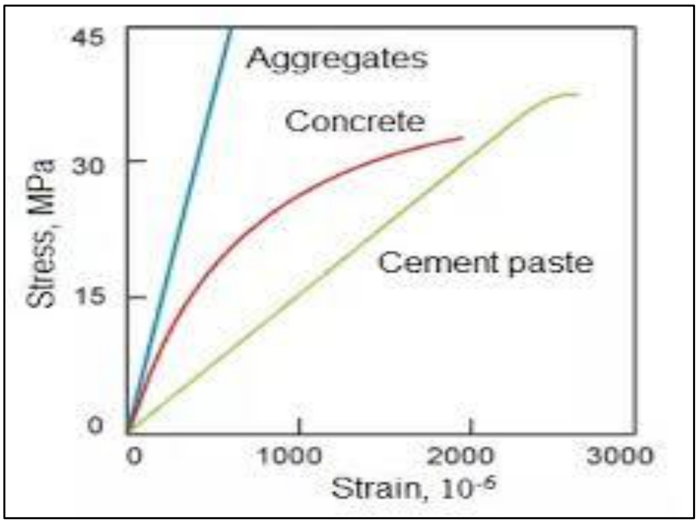
Elasticity, Shrinkage and Creep

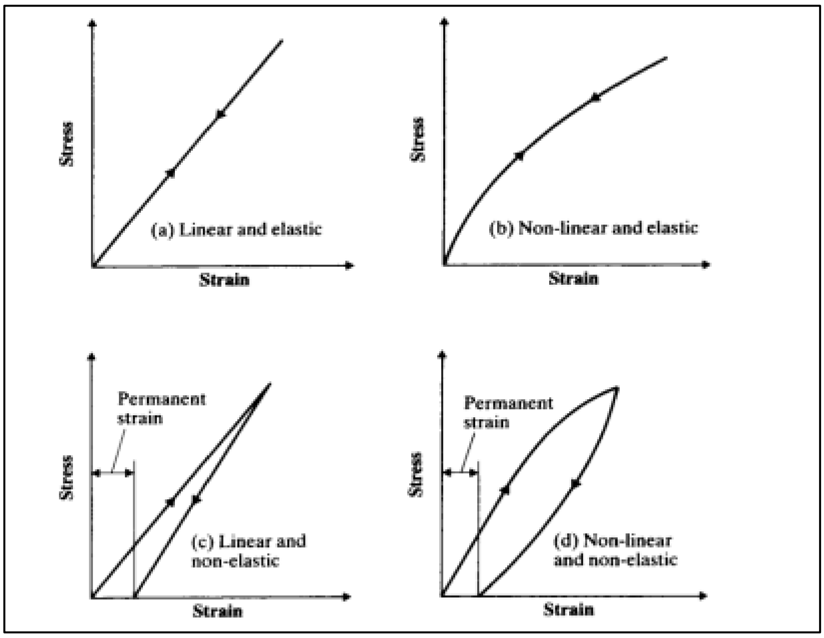
Elasticity is the property of a material by which the material regains its original shape when the load is withdrawn. It is known that concrete, like other structural materials, is elastic to a limited extent.

Concrete is a heterogeneous, multi-phase material, whose behavior is influenced by the elastic properties and morphology of its component materials. So, the stress-strain curve does not exactly does not follow Hooke's law. The components of concrete i.e. cement paste and aggregates, when individually subjected to loading, they show almost linear stress-strain relation. The cement paste has lower elastic modulus than the aggregate. The concrete behavior is somewhere in the middle of both.



Stress-Strain curves for Cement paste, aggregate and Concrete

Classification of material behavior in engineering



Modulus of Elasticity

The modulus of elasticity of a material is defined by the slope of the stress-strain curve. The higher the elastic modulus, the more resistant the material is to deformation. Concrete is not a perfectly elastic material and therefore the stress-strain curve indicates a varying elastic modulus (the slope of the tangent).

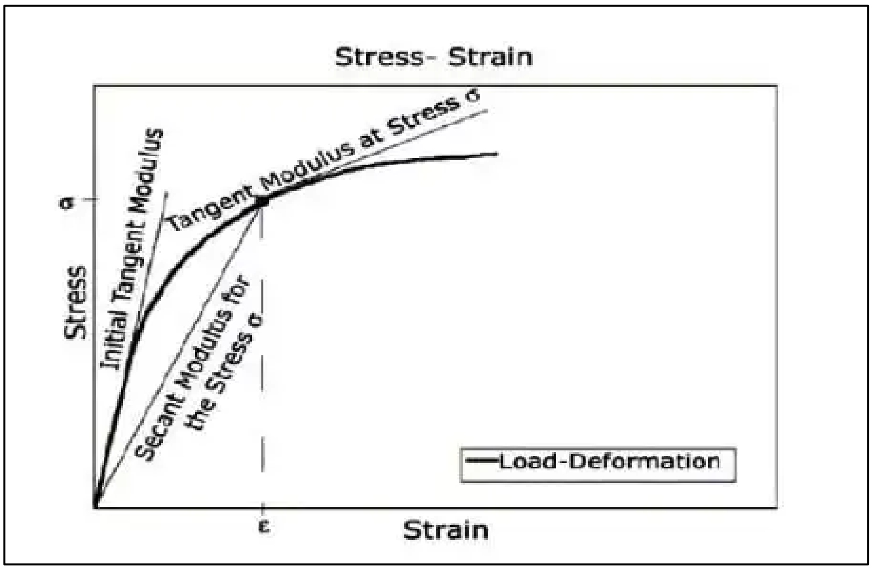
Determination the Modulus of Elasticity for Concrete

There are several methods to estimate the concrete modulus of elasticity from the stress-strain curve:

1- **Young's modulus:-** This is called the **initial tangent modulus** can be applied only to the linear portion of the stress-strain curve. However, its practical significance is limited as it can only be utilized under very low stresses, and estimating its value is not easy.

2- **Tangent modulus:-** The slope of the tangent at any given point. This coefficient only applies to very slight variations in load above or below the specified load for measuring the coefficient of friction, thus its practical significance is also limited.

3- **Secant modulus or static modulus of elasticity:-** It is the common elastic modulus of concrete. It is given by the slope of the line drawn connecting a specified point on the curve to the origin of the curve. Its value depends on the rate of load application.



Dynamic Modulus of Elasticity

The usual method for estimating dynamic modulus of elasticity typically involves subjecting a specific vibration to a concrete model in the form of a cylinder or beam and measuring the amount of vibrations. Then, a specific equation is used to calculate it.

The dynamic modulus of elasticity is typically approximately equal to the initial tangent modulus calculated from static testing. Additionally, it is usually much larger than the secant modulus.

The following equation illustrates the relationship between dynamic and static modulus of elasticity:

$$Ec = 1.25Ed - 19$$

Where Ec and Ed represent the static and dynamic modulus of elasticity respectively. Note that this relationship does not apply to concrete containing lightweight aggregate or concrete containing more than 500 kg of cement per cubic meter.

Factors effecting on the modulus of elasticity

Generally, the factors that affect the strength of concrete also affect the modulus of elasticity in a similar manner, but typically to a lesser extent.

1- **Strength of concrete:-** The modulus of elasticity increases as the concrete's strength increases. It is noticeable that the elasticity modulus of concrete increases approximately with the cubic root of its strength.

2- **The conditions of the specimen during testing:**
The wet specimen has a higher modulus of elasticity than the dry specimen, while the strength varies in the opposite direction.

3- **The properties of aggregate:-** The properties of the aggregate affect the modulus of elasticity, although they do not significantly affect the compressive strength. The higher the modulus of elasticity of the aggregate, the higher the modulus of elasticity of the resulting concrete.

4- **Mix proportion:-** In general, aggregate has a higher modulus of elasticity than cement paste.
The modulus of elasticity of lightweight aggregate concrete is approximately similar to that of cement paste. Therefore, the

mixing ratios do not significantly affect the modulus of elasticity of lightweight aggregate concrete.

5- **The age of the concrete specimen:-** The modulus of elasticity increases at a faster rate in later ages compared to the strength.

6- **Curing temperature:-** If the strength of concrete mixes is equal, then the modulus of elasticity will be higher to some extent as the early curing temperature decreases. Thus, steam-cured concrete has a lower modulus of elasticity compared to water-cured concrete with the same strength, but the difference is less than 10%.

Shrinkage of Concrete

Shrinkage of concrete is the time-dependent strain measured in an unloaded and unrestrained specimen at constant temperature The term shrinkage is used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.

Types of concrete shrinkage

a) **Plastic Shrinkage :** Shrinkage of this type appears soon after the concrete is placed in the forms while the concrete is still in the plastic state. The reason for this type of shrinkage is the loss of water , either through absorption by the aggregate or evaporation from the concrete surface. The loss of water results in the reduction of volume. The presence of aggregate particles and reinforcement bars inhibits the settlement within the concrete, resulting in the appearance of surface or internal cracks around the aggregate or reinforcement.

b) **Drying Shrinkage:** The withdrawal of water from concrete placed in unsaturated air causes drying shrinkage. A portion of this localized movement is irreversible and it is necessary to distinguish it from reversible moisture transfer resulting from alternating storage effects under moisture and dry conditions.

c) **Autogenous Shrinkage:** In a conservative system i.e. where no moisture movement to or from the paste is permitted, when the temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as an autogenous shrinkage. Autogenous shrinkage is of minor importance and is not applicable in practice to many situations except that of a mass of concrete in the interior of a concrete dam.

d) **Carbonation Shrinkage:** Concrete undergoes another type of shrinkage when carbon dioxide in the air reacts, in the presence of moisture, with hydrated cement compounds. The action of carbon dioxide takes place even if its concentration in the air is low. The rate of carbonation increases with the increase in carbon dioxide concentration. As a result of this reaction, calcium hydroxide saturates with carbon dioxide, forming calcium carbonate, and other cement compounds decompose.

Shrinkage Mechanism:

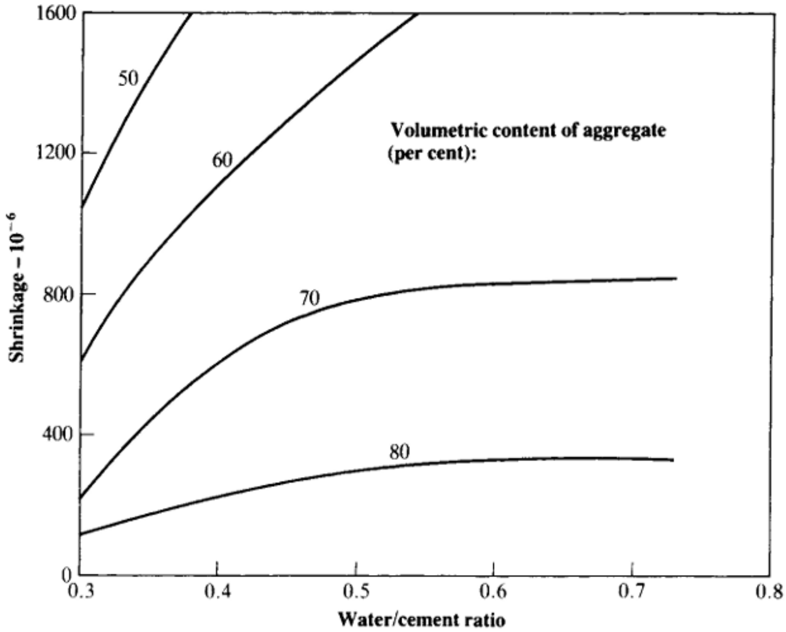
The change in volume of dry concrete is not equal to the volume of water lost. The loss of free water, which occurs initially, may cause a very small portion of the shrinkage, but as drying continues, the water adhering to the surface of the gel particles disappears.

Cement paste treated with high-pressure steam, which has a low surface area, shrinks 5 to 10 times less than the comparable paste treated conventionally with water.

Factors Affecting on the Shrinkage

- Type and quantity of aggregate
- Water content
- The modulus of elasticity of concrete
- Cement fineness
- Use of additives
- Curing period
- Relative humidity

The shrinkage is directly proportional to the water-cement ratio and inversely proportional to the aggregate-cement ratio as shown in the Figure below.

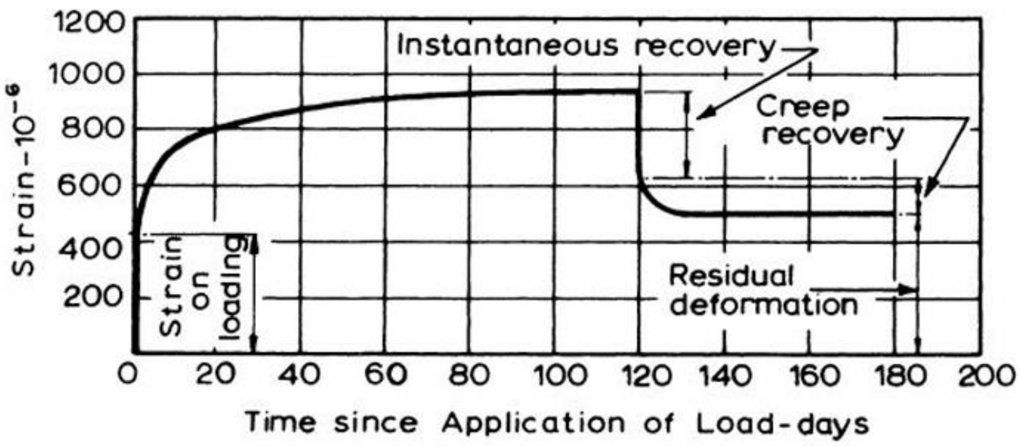


Effect of water/cement ratio and aggregate content on the shrinkage

Creep of Concrete

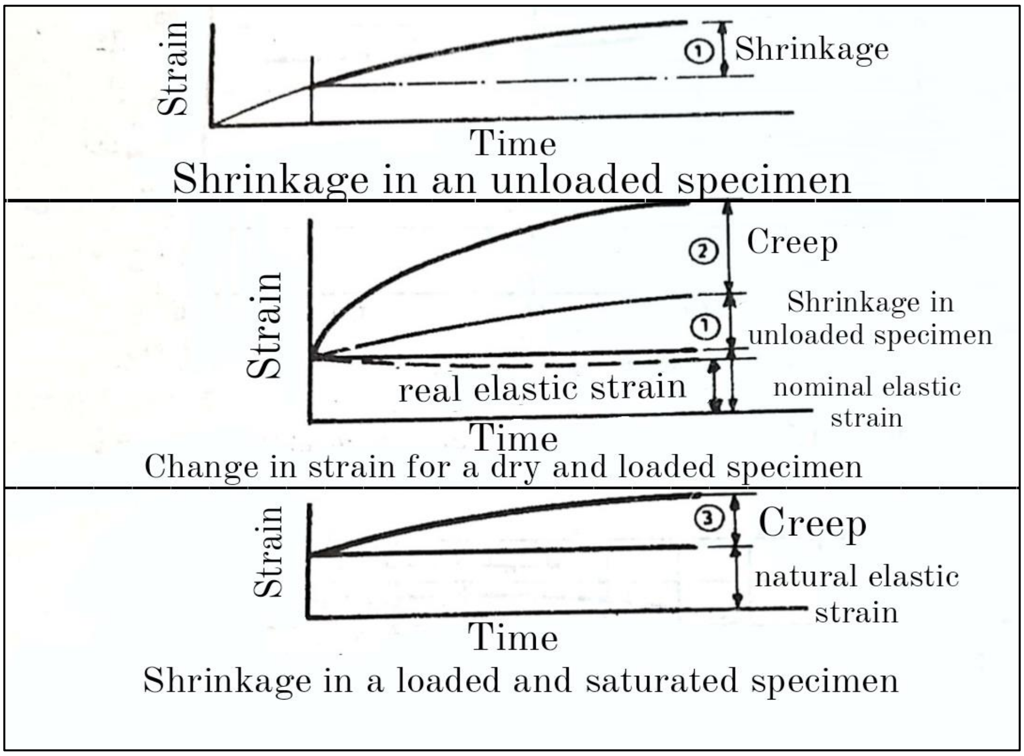
Creep is the increase in strain that occurs under the influence of permanent loads.

When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called instantaneous strain. Then, if the load is maintained for a considerable period of time, concrete undergoes additional deformations even without any increase in the load. This time-dependent strain is termed as creep.



❖ creep in concrete kept under certain conditions, preventing shrinkage or swelling, has been considered. However, if the specimen is exposed to drying at the same time that the load is applied, it is generally assumed that creep and shrinkage are additive. Therefore, creep is calculated from the difference between the total deformation of the loaded specimen and the shrinkage of a similar unloaded specimen preserved under the same conditions and for the same period.

❖ When the applied load is removed from the specimen, the strain decreases immediately by an amount equal to the elastic strain at the given age, and generally to a lesser extent than the elastic strain during loading. This instantaneous recovery is followed by a gradual decrease in strain, referred to as creep recovery as shown in the figure above, indicating that creep is not a simple reversible phenomenon.



Factors influencing creep

1. **Strength of concrete :** Creep is inversely proportional to the concrete strength.
2. **Applied stress level:** Creep increases with increasing applied stress.
3. **Ambient relative humidity:** Creep increases with decreasing relative humidity of the concrete. Additionally, exposing specimens to alternating wetting and drying increases creep.
4. **The size and shape of the specimen:** Creep decreases with increasing size of the specimen.
5. **The temperature:** The creep rate increases with increasing temperature.
6. **Age of concrete:** The rate of creep decreases with time.

7. **The effect of the aggregate:** Normal weight aggregate exhibits negligible creep, thus the primary contributor to creep is the cement paste. Therefore, the influence of the aggregate is to reduce the effective creep in concrete
8. **Other factors :** The type and fineness of cement, Modulus of elasticity and the water/cement ratio.

Effects of creep

- Creep affects deformations and deflections and often also influences stress distributions. However, these effects vary depending on the type of structure.
- Creep in normal concrete does not significantly affect the strength itself, although under very high stresses, it accelerates reaching the ultimate strain, which leads to failure.
- In reinforced concrete columns, creep gradually transfers the applied load from the concrete to the reinforcement steel.
- Creep may lead to cracking in mass concrete when subjected to a cycle of temperature change due to hydration heat and subsequent cooling. Therefore, controlling the temperature rise within the massive concrete block is necessary by using low-heat cement, reducing cement content, cooling mix components, or cooling the concrete, among other methods.
- In all concrete structures, creep reduces internal stresses resulting from irregular shrinkage, consequently reducing the occurrence of cracks.