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EXPERIMENTAL INVESTIGATION OF CHANGE IN PARTIAL FACTOR OF SAFETY OF CONCRETE WITH CHANGE IN STRENGTH

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ABSTRACT - The strength of any material obtained in a structure is always less than the characteristic strength of the material. It is because of the workmanship or quality control in the manufacture of materials. The reduced value of strength which is obtained by applying partial safety factors to the characteristic strength is called as design strength of the material. A higher value of partial safety factor for concrete i.e., 1.5 has been adopted in IS 456:2000 because of the fact that there are greater chances of variation of strength of concrete due to improper compaction, inadequate curing and variation in the properties of ingredients. The chances of variation in the properties of steel are small, as it is fabricated in the factories where good workmanship and better quality control can be an achieved. Hence, a lower value of 1.15 has been adopted.

In this study, the influence of various parameters affecting the compressive strength of concrete such as type of materials used, water-cement ratio, aggregate size and curing period are experimentally studied. Also how the change in compressive strength affects the value of partial safety factor is studied. For the experimental research, M20 grade of concrete is chosen with coarse aggregate size of 12 mm, 20 mm and 40 mm with a water-cement ratio of 0.4 and 0.5 respectively. A set of specimens containing 9 cubes, 3 cylinders and a beam of each combination of selected material properties are cast and cured for a period of 7, 14 and 28 days. The study aims at decreasing the value of partial safety factor of concrete by experimental study of change in strength with respect to change in factors affecting the strength. The experimental results are validated using STAAD Pro.

Keywords: *Concrete, strength, partial safety factor, design strength, compaction, water-cement ratio*

1. INTRODUCTION

Concrete is the combination of two types of materials, one is binding material and second is the filler material. Thus, it is a composite material where in a paste of cement, made with water, on solidification binds firmly together the various particles of inert materials like sand and stone ballast. The inert material called "aggregates" are well graded in size from fine sand to pebbles or stone ballast to brick ballast. Cement concrete is an extremely versatile material of construction which is used for variety of works ranging from small cottages to massive dams and bridges.

The quality of concrete is judged largely on the strength of that concrete. Obviously, the strength of any structure, or any part of a structure is important. The strength of concrete is commonly considered as its most valuable property, although in many practical cases, other characteristics, such as durability and permeability may in fact be more important. Strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. It is almost invariably a vital element of structural design and is specified for compliance purposes. Strength of concrete could be defined as the ultimate load that causes failure (or is its resistance to rupture) and its units are force units divided by area (N/mm^2).

2. STRENGTH OF CONCRETE

The characteristic strength of concrete is the definite theoretical value of the material in which, when the material has actually tested the probability of getting higher results higher than that value is 95% or say the probability of getting the result lower than that value 5%. Thus, the characteristic strength is the value of design material along with consideration of its probable variability.

The strength of concrete generally represents the compressive strength of concrete, as concrete has maximum compressive strength and is its unique feature. Therefore, in concrete the characteristic strength of concrete literally means Characteristic compressive strength unlike in other materials like steel or wood, etc. so most of the design of the concrete structure is done by adopting the value of compressive strength. And also compressive strength is well used to relate much property of concrete such as elasticity modulus, water tightness, porosity, wear resistance, fire resistance, etc. the tensile strength of concrete is usually 10 percent of the compressive strength, as concrete is very weak in tension.

3. PARTIAL SAFETY FACTOR OF CONCRETE

The partial safety factor method is a design method by which the target safety class is obtained as closely as possible by applying load and resistance factors to characteristic values of the governing variables. In general, limit state design makes use of the concept of design strengths and design loads, obtained by applying partial safety factors and other factors such as the combination factors to characteristic or representative values of strengths or loads.

In limit state concept of design as per IS 456:2000, (Cl. 36.3.1), the design strength of materials, f_d is given by dividing the characteristic strength of the material by partial safety factor appropriate to the material and the limit state being considered.

$$f_d = f/\gamma_m$$

where f = characteristic strength of the material, and

γ_m = partial safety factor of the considered material.

A structure attaining a limit state may have serious consequences such as huge loss of life and disruption of the economy, therefore higher values of partial safety factors are being considered. When assessing the strength of a structure or structural member for the limit state of collapse, as per IS 456:2000, the values of partial safety should be taken as 1.5 for concrete and 1.15 for steel.

4. MODIFICATION OF PARTIAL SAFETY FACTORS FOR MATERIALS

Annex A of Eurocode 2 (BS EN 1992-1-1:2004) provides recommendations for reduced partial safety factors for materials. The modification criteria for in-situ concrete structures and precast products are given. The reduction of partial safety factor based on quality control and reduced deviations, based on using reduced or measured geometrical data in design and reduction based on assessment of concrete strength in finished structure are pointed out under in-situ concrete structures.

There are several factors affecting the strength of concrete which in turn affects the partial safety factor itself. Each of these factors have independent or combined effect indetermining the strength of concrete structures or elements. In Eurocode 2, some of these factors were studied in order to control the quality of materials used and to determine the strength variation of concrete elements.The partial safety factor for steel is taken as 1.15 whereas it is 1.5 for concrete as per IS 456:2000. This clearly states that the strength of concrete is far underestimated than the strength of steel. Uncertainty in strength of concrete is more than that of steel because steel is manufactured in controlled conditions whereas concrete is made in the site itself. Because of the greater chances of variation of strength of concrete due to variation in quality of materials, improper compaction, inadequate curing and variation in the properties of concrete etc., higher FOS is taken for concrete to account for the uncertainty.

5. FACTORS AFFECTING PARTIAL SAFETY FACTOR OF CONCRETE

Concrete strength is affected by many factors, such as quality of raw materials, water/cement ratio, coarse/fine aggregate ratio, age of concrete, compaction of concrete, temperature, relative humidity and curing of concrete.

5.1 Quality of raw materials

The main ingredients of concrete are cement, sand, aggregate and water. Quality of each material affects the strength of the concrete. All materials, therefore, should fulfil the standard criteria for use in concrete.

(a) Type and Quantity of Cement

The quantity of cement greatly affects concrete strength. The higher cement content increases the tendency of shrinkage cracks when the concrete is getting cured and hardened. Types of cement also have a great impact on the properties of hardened concrete. According to IS 456 2000, the minimum cement content specified ranges from 300 to 360 kg per cubic meter of concrete for various exposure conditions and for various grades of concrete. Maximum cement content in concrete is also limited to 450 kg per cubic meter of concrete. The grade of cement – i.e., 33 grade, 43 grade, 53 grade will also affect the strength of concrete. The higher the grade, the higher strength particularly high early strength.

(b) Types and Quantity of Aggregate

The strength of concrete depends upon the strength of aggregates. Low quality of aggregate reduces the strength of concrete. The quantity of aggregate also affects the properties of hardened concrete. At constant cement content, the higher amount of aggregate reduces the concrete strength. The shape and grading of aggregate play a major role as far as strength of concrete is concern.

(c) Quality of Water

Quality of water plays a significant role in the setting and hardening process of concrete. Acidic, oily, silty, and seawater should not be used in concrete mix. Impurities of water give an adverse effect on the strength of concrete. Therefore, potable water is always used in concrete mix.Particularly the impure water may lead to corrosion, carbonation or acid attack, therefore, reduces the life of concrete.

5.2 Water-cement ratio

The ratio of the weight of water to the weight of cement is called water/cement ratio. It is the most important factor for gaining the strength of concrete. The lower w/c ratio leads the higher strength of concrete. Generally, the water/cement ratio of 0.45 to 0.60 is used. Too much water leads to segregation and voids in concrete. Water/cement ratio is inversely proportional to the strength of concrete. As shown in the chart below when the w/c ratio is increased the strength of concrete gets decreased and when w/c ratio is decreased then the strength of concrete increases.

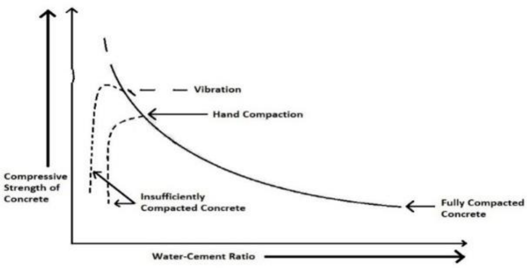


Fig. 1 Compressive strength of concrete vs Water-Cement ratio

5.3 Shape of aggregates

There are many shapes of aggregate like angular, cubical, elongated, elongated and flaky, flaky, irregular and rounded.

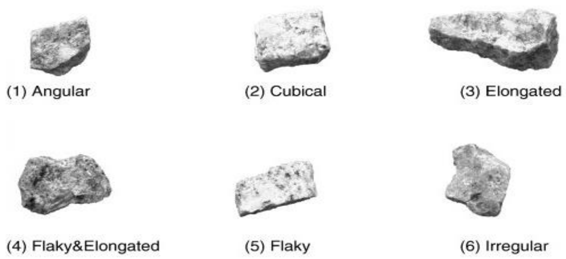


Fig. 2 Shapes of coarse aggregates

Angular aggregates are rough textured, and rounded aggregates are smooth textured. Thus, the rounded aggregates, create the problem of lack of bonding between cement paste and aggregate. Angular aggregates exhibit a better interlocking effect in concrete, but the angular aggregate contains a larger amount of voids. For this, you needed well-graded aggregate. The shape of aggregates becomes more important in case of high strength and high-performance concrete where very low w/c ratio is used. In such cases, cubical shape aggregates with uniform grading are required for better workability.

5.4 Maximum size of aggregates

Larger size aggregates give a lower strength because they have a lower surface area for development of gel bond which is responsible for strength. Larger size aggregate makes concrete heterogeneous. It will not distribute loading uniformly when stressed. Due to internal bleeding, the problem of development of the microcracks in concrete happens when larger size aggregates are used in concrete.

5.5 Compaction of concrete

Compaction of concrete increases the density of the concrete because it is the process in which air voids are removed from freshly placed concrete which makes the concrete compact and dense. The presence of air voids in concrete greatly reduces its strength. Approximately 5% of air voids can reduce the strength by 30 to 40%. As we can see in the above chart, even at the same water/cement ratio strength is different with different compaction accuracies. In the fully compacted concrete, strength is higher than the insufficiently compacted concrete.

5.6 Curing of concrete

Curing of concrete is the most essential to prevent plastic shrinkage, temperature control, strength development and durability. Curing provides the desired moisture and temperature at the depth and near the surface after placing and finishing of concrete for development of strength. In other words, curing provides sufficient water to concrete for completing the hydration process without interruption which is important for strength development. Commonly 7-day curing corresponds to 70% of compressive strength. Curing period depends on the types of cement and the nature of work. Generally, it's about 7 to 14 days for Ordinary Portland Cement. There are many methods of curing like Ponding and immersion, Spraying and fogging saturated wet coverings etc.

5.7 Age of concrete

With increase in age of concrete, the degree of hydration would be more. Hydration process is the chemical reaction of water and cement. Hydration produces the gel which plays a significant role in the bonding of particles of the concrete ingredients. Therefore, the strength of concrete increases with its age. Normally, concrete strength gets doubled after 11 years provided there are no adverse factors.

The knowledge about factors which affect the concrete strength is helpful in many ways particularly during designing the structure, choosing material for concrete, observing precaution for different weather conditions, choosing different methods for concreting, aiming better life of building structures, for low maintenance of building after construction, longer durability and better serviceability etc.

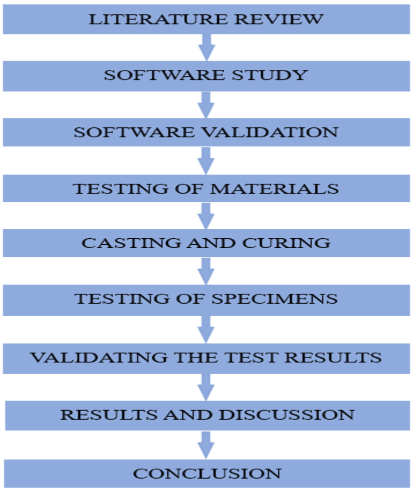
5.8 Temperature and humidity

Weather condition also affects the strength of concrete due to different reasons. In cold climate, exterior concrete is subjected to repeated freezing and thawing action due to the sudden change in weather. It produces deterioration in concrete. With the change in moisture content, materials expand and contract. It produced cracks in concrete. With the certain degree of temperature increase, the rate of hydration process increases in it which, it gains strength rapidly. Sudden temperature changes create a thermal gradient, which causes cracking and spalling of concrete. So that, the final strength of concrete is lower at the very high temperature.

6. OBJECTIVE

- To evaluate the influence of following factors on the compressive strength of concrete
  - Selection of raw materials
  - Water/cement ratio
  - Age of concrete
- To determine the change in partial safety factor of concrete with change in strength of concrete
- To validate the experimental results using STAAD Pro

7. METHODOLOGY



8. SPECIMEN DETAILS

The specimen mix designation details are shown below in Table.The alphabet CA indicates the coarse aggregate and the numeric preceding the alphabet indicates the size of coarse aggregate and the one succeeding indicates the water-cement ratio used in the specified mix.

Table 1 Mix designation for different specifications used

Sl. No.	Mix Designation	Coarse aggregate size (mm)	Water-cement ratio
1	CA124	12	0.4
2	CA125	12	0.5
3	CA204	20	0.4
4	CA205	20	0.5
5	CA404	40	0.4
6	CA405	40	0.5

For each mix 9 cubes, 3 cylinders and a beam were cast. The compressive strength test and split tensile strength test were carried out at 7, 14 and 28 days. The flexural strength test was carried out at 28th day. The details regarding the number of specimens used are shown below in Table.

Table 2 Details of Number of Specimens

Sl. No.	Specimen	Property	Size	Nos.
1	Cube	Compressive strength	150mm×150mm×150mm	54
2	Cylinder	Split tensile strength	150mm×300mm	18
3	Beam	Flexural strength	100mm×100mm×500mm	6
			Total	78

Mix proportion of M20 (1:1.5:3) mix as per IS 10262 is used for all the concrete mixes used in this work.


Fig.

Fig. 3 A set of specimens cast (CA405)

Table 3 Quantities of Materials Required for all the Concrete Mixes Chosen

Mix Designation	Materials			
	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)
CA124	21.24	31.86	63.72	8.49
CA125	20.41	30.61	61.23	10.20
CA204	21.42	32.13	64.26	8.56
CA205	20.56	30.84	61.68	10.28
CA404	21.51	32.26	64.53	8.60
CA405	20.64	30.96	61.92	10.32

9. EXPERIMENTAL RESULTS

Compressive strength is the capacity of material or structure to resist or withstand under compression. The compressive strength of a material is determined by the ability of the material to resist failure in the form of cracks and fissures. In this test, the push force applied on both the faces of concrete specimen and the maximum compression that concrete bears without failure is noted. Concrete testing helps us to majorly focus on the compressive strength of concrete because it helps us to quantify the ability of concrete to resist compressive stresses among structures where-as other stresses such as axial stresses and tensile stresses are catered by reinforcement and other means.

The testing was done in the Compression Testing Machine and the load was applied at a rate of 14 N/mm^2/min, then the failure load was noted and the compressive strength was calculated.

Compressive strength of concrete cube = $\frac{P}{A}$

where,

P = Maximum load at failure

A = cross-sectional area

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The test results and the variation of 7, 14 and 28 days compressive strength is shown in Table.

Table 4 Compressive Strength of Concrete Cubes

Sl. No.	Mix Designation	Average Compressive Strength (N/mm^2)		
		7 Days	14 Days	28 Days
1	CA124	19.70	20.88	23.36
2	CA125	15.25	17.18	19.25
3	CA204	20.29	23.09	25.34
4	CA205	19.25	20.73	23.99
5	CA404	19.10	25.62	27.84
6	CA405	18.80	20.58	25.47

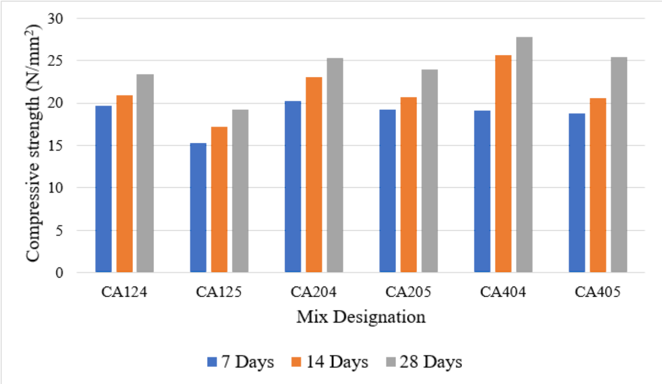

Fig. 4 Variation of Compressive strength

From the above graph, it is clear that the concrete mix with coarse aggregate of 20mm size and a water-cement ratio of 0.4 (CA204) gives higher average compressive strength of value 20.29 N/mm^2in 7 days but with an age of 28 days, it is clear that the concrete mix having coarse aggregate size 40mm and a water-cement ratio 0.4 (CA404) gives higher average compressive strength of 27.84 N/mm^2.

The split tensile strength test is an indirect test used for determining the tensile strength of concrete. Here the cylindrical specimens were placed with its axial horizontal between the plates of the testing machine and load was applied at a rate of 1.2 N/mm^2/min to 2.4 N/mm^2/min, then the load at failure occurred by a splitting in the vertical diameter of specimen was noted. The test results and variation in split tensile strength was shown in Table 8.2.

Split tensile strength of concrete cylinder, $T = \frac{2P}{\pi DL}$

where,

P = Maximum applied load indicated by testing machine in Kn

D = Diameter of the cylinder

L = Length of the cylinder

Table 5 Split Tensile Strength of Concrete

Sl. No.	Mix Designation	Split Tensile Strength (N/mm^2)		
		7 Days	14 Days	28 Days
1	CA124	1.83	1.55	1.98
2	CA125	1.55	1.69	1.75
3	CA204	2.14	2.26	2.91
4	CA205	1.98	2.12	2.29
5	CA404	2.12	2.54	3.11
6	CA405	1.83	2.12	2.33

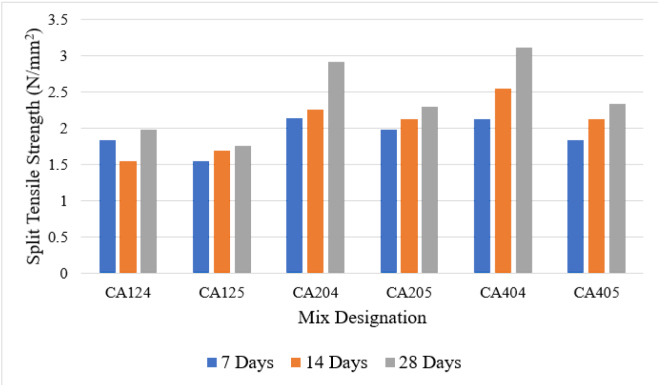

Fig. 5 Variation of Split Tensile Strength

From the above graph, it is clear that the maximum split tensile strength of 2.14 $N/mm^2$was obtained by the concrete mix having coarse aggregate size 20mm and a water-cement ratio of 0.4 (CA204) at 7 days and a split tensile strength value of 3.11 $N/mm^2$was obtained by the concrete mix having coarse aggregate size 40mm and a water-cement ratio of 0.4 (CA404) at 14 and 28 days.

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. Concrete is strong in compression and weak in tension. The tensile stresses are likely to develop in concrete due to drying shrinkage, temperature gradients and many other reasons. Therefore the knowledge of tensile strength is important.

Flexural strength of concrete beam, $F_b = \frac{Pl}{bd^2}$

Where,

P = Failure load in kN

l = Length of the beam in m

b = breadth of the beam in m

d = depth of the beam in m

Tests were carried out on 100mm×100mm×500mm size beams conforming to IS 516:1959 and the load was applied at a rate of 1.8 kN/min.

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The test results and variation in flexural strength are shown below.

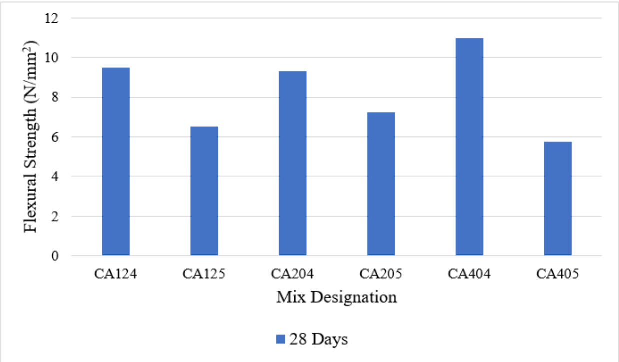

Fig. 6 Variation of Flexural Strength of Concrete Beam

From the above graph, it is clear that a maximum flexural strength of 11 N/mm^2 was obtained by the concrete mix having coarse aggregate size of 40mm and a water-cement ratio of 0.4 (CA404) at 28 days.

10. VALIDATION OF EXPERIMENTAL RESULTS USING STAAD-PRO

The experimental results shown in chapter 8 reveals that the mix designation CA404 has shown better results in compressive strength, split tensile strength and flexural strength. In order to validate these results, two frames, each having a compressive strength of 20 N/mm^2 and 27.84 N/mm^2 modelled and analysed for the maximum deflection using Staad-Pro.

MODEL NAME	COMPRESSIVE STRENGTH (N/mm^2)
FCK 20	20
FCK 27	27.84

FRAME 1 - FCK 20

The dimensions and properties of the first frame named FCK 20 is shown in Fig. 8 and Fig. 9 respectively and the load distribution details are shown in Fig. 10.

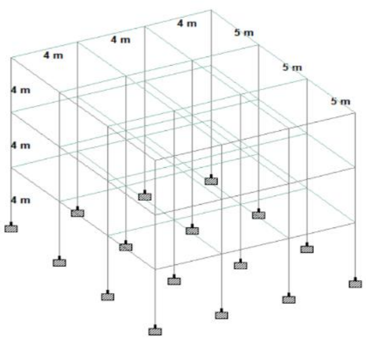

Fig. 7 Frame – FCK 20

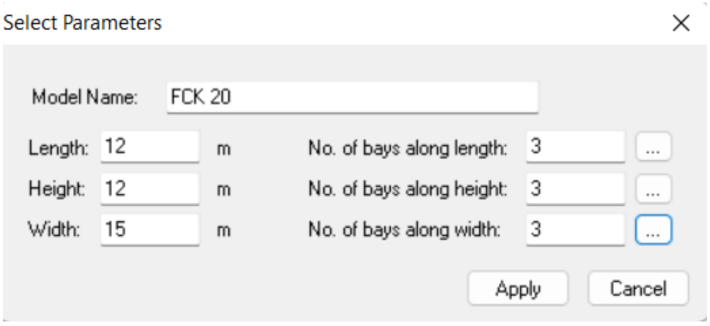

Fig. 8 Dimensions of FCK 20

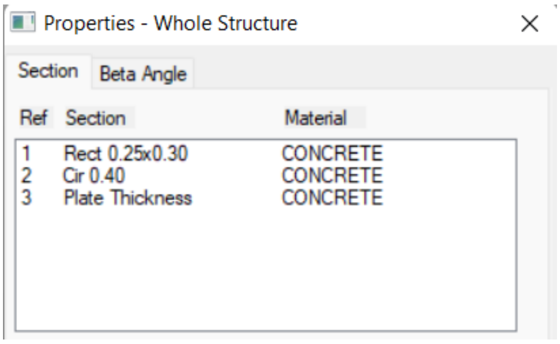

Fig. 9 Properties of frame members

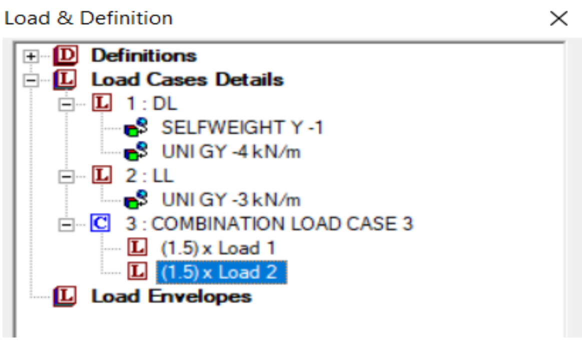

Fig. 10 Load distribution details

As it is earlier mentioned, frame FCK 20 is modelled with a concrete compressive strength 20 N/mm^2 (Fig 11).

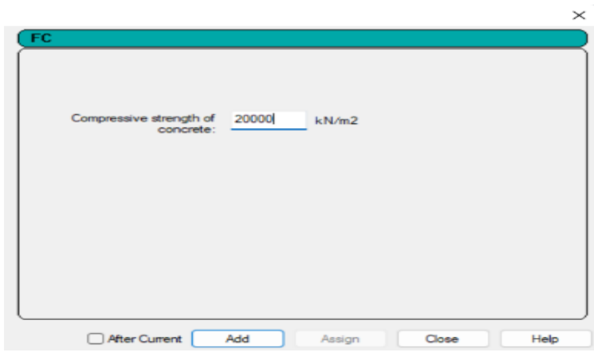

Fig. 11 Compressive strength of concrete

The maximum deflection experienced by the frame member is 5.192 mm and the deflection diagram is shown in Fig.12

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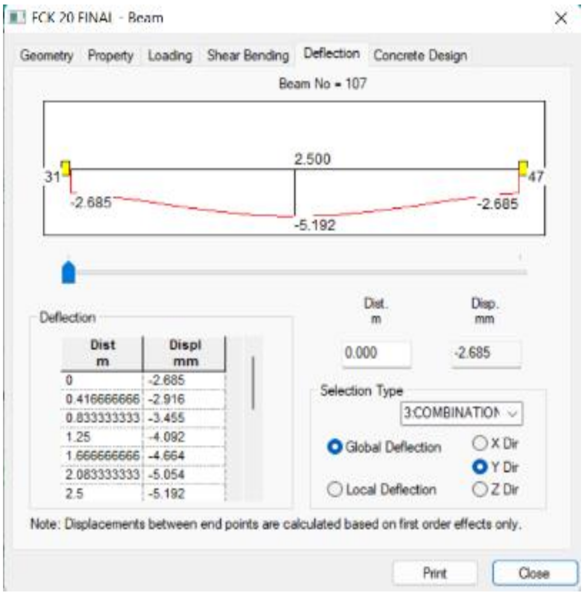

Fig. 12 Maximum deflection

FRAME 2 – FCK 27

The dimensions and properties of the first frame named FCK 20 is shown in Fig.14 and Fig. 15 respectively and the load distribution details are shown in Fig. 16.

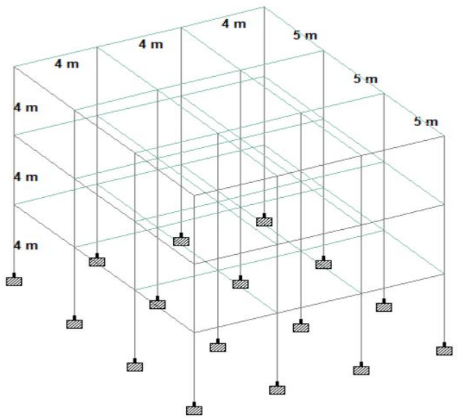

Fig. 13 Frame – FCK 27

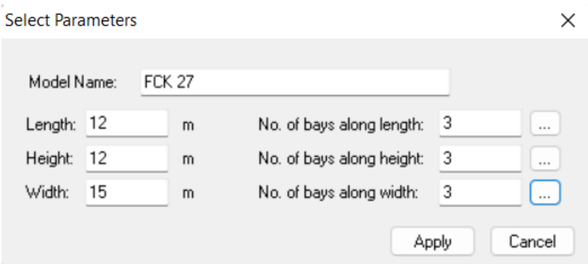

Fig. 14 Dimensions of FCK 27

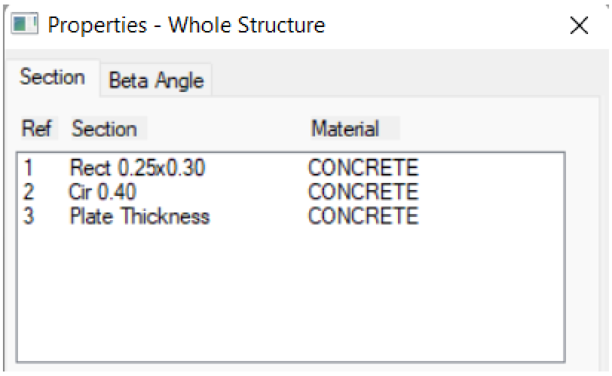

Fig. 15 Properties of frame members

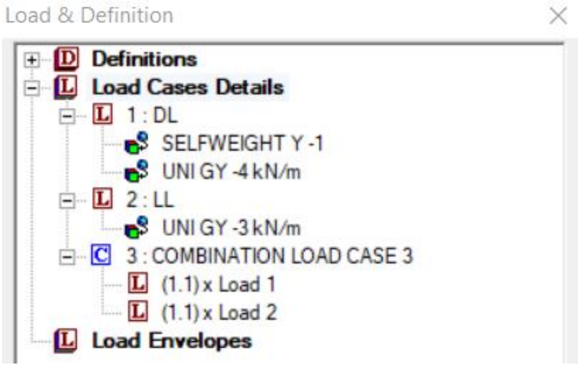

Fig. 16 Load distribution details

As it is earlier mentioned, frame FCK 20 is modelled with a concrete compressive strength 20 N/mm^2.

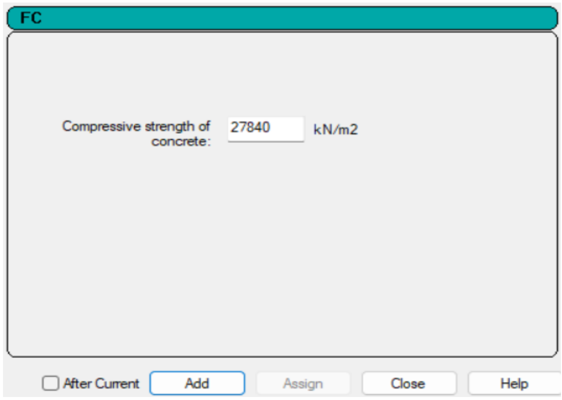

Fig. 17 Compressive strength of concrete

The maximum deflection experienced by the frame member is 3.807 mm and the deflection diagram is shown in Fig.

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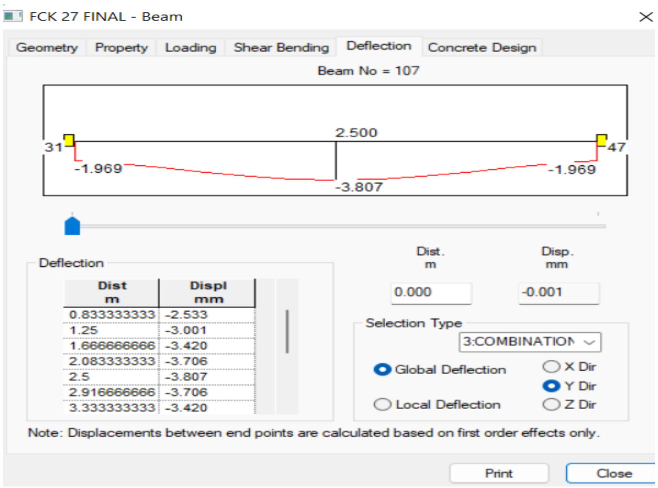

Fig. 18 Maximum deflection

11. DETERMINATION OF PARTIAL SAFETY FACTOR WITH CHANGE IN COMPRESSIVE STRENGTH

The design strength of concrete and steel is obtained by dividing the respective characteristic strengths by appropriate partial safety factors for concrete and steel. The partial safety factor for concrete and steel is 1.5 and 1.15 respectively. The safety factor for concrete is higher than that for steel because the quality of concrete is more uncertain compared to steel. The partial safety factor ensures that the actual strength of the material is higher than the design strength, which results in a safer and more reliable design. The Eurocode 2 permits a reduction in partial safety factor for materials like concrete and reinforcing steel. This results in reduction in material quantity.

The design strength of materials, f_d is given by

$$f_d = \frac{f}{\gamma_m}$$

where

f = characteristic strength of the material

γ_m = partial safety factor appropriate to the material

For permissible compressive stress in concrete is taken as 0.67 f_{ck} and a partial factor of safety of 1.5 is applied to it. So, the final stress comes out to be 0.45 f_{ck}. For design purposes, the compressive strength of concrete is assumed to be 0.67 times the characteristic strength of concrete.

Thus the above equation becomes

$$0.45\, f_{ckd} = \frac{0.67\, f_{ckc}}{\gamma_m}$$

From the above equation, the partial safety factor of concrete can be found out as,

$$\gamma_m = \frac{0.67\, f_{ckc}}{0.45\, f_{ckd}}$$

f_{ckc} = characteristic compressive strength of concrete mix

f_{ckd} = compressive strength of concrete found out experimentally

Thus,

$$\gamma_m = \frac{0.67 \times 20}{0.45 \times 27.84}$$

$$\gamma_m = 1.069 \approx 1.1$$

12. CONCLUSION

In the normal case, the partial safety factor for concrete is considered as 1.5. In the same concrete mix proportion of M20, by varying the aggregate size and water-cement ratio, significant variation in compressive strength, split tensile strength and flexural strength are noted for all the mixes chosen namely CA124, CA125, CA204, CA205, CA404, CA405.

- The 28 days average compressive strength of concrete cubesfor the mix designation CA404 having the coarse aggregate size 40mm and water-cement ratio 0.4 is 27.84 N/mm^2 which is approximately 14% increase from the normal value.
- The 28 days average split tensile strength of concrete cylinders for the mix designation CA404 having the coarse aggregate size 40mm and water-cement ratio 0.4 is 3.11 N/mm^2, which is the highest among all the mixes chosen.
- The 28 days average flexural strength of concrete beams for the mix designation CA404 having the coarse aggregate size 40mm and water-cement ratio 0.4 is 11 N/mm^2, which is the highest among all the mixes chosen.
- The experimental results of compressive strength was validated using STAAD Pro by determining the deflection.
- In software validation, there is a great variation in deformation.Deflection of Frame 20 was 5.192 mm and the same for Frame 27 was 3.807 having a percentage decrease of 26.67.
- By calculating partial safety factor with the help of characteristic compressive strength obtained from experiment and actual compressive strength, the obtained value for partial safety factor is 1.069, which is approximately equal to 1.1.
- It can be concluded that by increasing aggregate size and decreasing water-cement ratio, FOS can be decreased to 1.1 from 1.5.

13. FUTURE SCOPE

Factors affecting the strength of concrete other than aggregate size and water-cement ratio can be considered.

Experimental results can be followed by more detailed theoretical study.

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