

COMPARISON OF DIFFERENT BEAM SIZES BASED ON DEFLECTION AND BENDING MOMENT

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ABSTRACT

Beams are the principal horizontal members of a reinforced concrete framed building. They collect loads from slabs and walls and transfer them to columns, and their size has a direct influence on the strength, stiffness, headroom, and cost of the structure. The depth of a beam in particular controls its flexural stiffness, and a small change in depth can produce a large change in deflection. In practice, beam sizes are often chosen from span-to-depth thumb rules and reused across projects without checking how the choice affects bending moment distribution, deflection, and reinforcement. The present study compares different beam sizes in an RCC frame on the basis of deflection and bending moment.

A G+4 storey RCC framed building with a plan of 18 m by 12 m, typical beam span of 6 m, and storey height of 3 m is modelled in STAAD.Pro. Five beam cross sections are considered, namely 230 mm by 380 mm, 230 mm by 450 mm, 300 mm by 450 mm, 300 mm by 525 mm, and 300 mm by 600 mm, while column sizes, slab thickness, loading, and material grades of M25 and Fe500 are kept the same. Dead and live loads are applied according to IS 875 (Parts 1 and 2), and seismic loads for Zone II are applied according to IS 1893 (Part 1):2016.

For each beam size the frame is analysed under limit state load combinations, and the maximum sagging and hogging bending moments, shear forces, mid-span deflections, and lateral storey displacements are recorded. The beams are designed according to IS 456:2000, and the required reinforcement and the deflection check based on span-to-effective-depth ratio are evaluated. The short-term elastic deflection from analysis is compared with the permissible limit of span divided by 250.

The results show that increasing the beam depth reduces the mid-span deflection sharply, approximately in inverse proportion to the cube of the depth, while increasing the width has a much smaller effect. The bending moments change moderately with beam size, because a stiffer beam attracts a larger share of the joint moment from the columns and its self-weight increases. Deeper beams require less tensile reinforcement for the same moment, and the smallest sections fail the span-to-depth deflection check or require compression steel.

The study concludes that a beam depth of about one twelfth of the span, combined with a width of 300 mm, gives a balanced solution for the building considered, satisfying deflection limits with a moderate steel percentage. The comparison demonstrates how analysis software can be used to select beam sizes rationally rather than relying on thumb rules alone.

I. INTRODUCTION

The structural frame of a typical reinforced concrete building consists of slabs, beams, columns, and foundations. Among these, beams play an important role in both gravity and lateral load resistance. Under gravity loads, they carry the slab reactions and wall loads over the span and transfer them to the columns. Under lateral loads, they form

part of the moment-resisting frame together with the columns and contribute to the lateral stiffness of the building. The size of the beams therefore affects the behaviour of the whole frame, not only of the individual member.

The two main requirements in beam design are strength and serviceability. Strength requires that the beam resist the factored bending moment and shear force with an adequate margin of safety, while serviceability requires that deflection and cracking remain within acceptable limits under service loads. IS 456:2000 controls deflection indirectly through limiting ratios of span to effective depth, with a basic value of 20 for simply supported beams and 26 for continuous beams, modified by factors for the tension and compression reinforcement. The code also limits the final deflection to span divided by 250.

Beam size is frequently decided at the architectural planning stage, where the depth must be kept small to maintain headroom and to allow services to pass below the beams, and the width is often matched to the thickness of the masonry wall above. Shallow beams satisfy architectural preferences but may lead to excessive deflection and cracking of partitions and finishes, and they may need heavy reinforcement. Deep beams are stiffer and more economical in steel but increase the storey height and self-weight. A balanced choice requires knowledge of how deflection and bending moment change with beam size.

The present work examines this question through a comparative study in STAAD.Pro. Five beam sizes are used in otherwise identical models of a G+4 RCC building, and the variation of bending moment, shear force, deflection, lateral displacement, and reinforcement is studied. The objective is to identify an appropriate beam size for the given span and loading and to illustrate the relationship between beam stiffness and structural response.

II. LITERATURE SURVEY

The flexural behaviour of reinforced concrete beams has been studied since the early development of reinforced concrete, and the basic relationships between moment, curvature, and deflection are well established. Elastic theory shows that the deflection of a beam under a given load is inversely proportional to its flexural rigidity, which is the product of the modulus of elasticity and the moment of inertia. Because the moment of inertia of a rectangular section is proportional to the width and to the cube of the depth, deflection is far more sensitive to depth than to width. Researchers studying reinforced concrete beams have added that cracking reduces the effective moment of inertia below the gross value, and that the effective stiffness depends on the reinforcement ratio and the level of applied moment. Formulations such as the effective moment of inertia approach, which interpolates between the cracked and uncracked stiffness, have been adopted in several codes and are referred to in Annex C of IS 456:2000 for the calculation of short-term deflection.

Studies on deflection control have compared the span-to-depth ratio approach with explicit calculation of deflection. The span-to-depth approach, used in IS 456:2000, is simple and convenient for routine design, and researchers have found that it gives safe results for most normal beams. However, investigators have also shown that it can be conservative for lightly loaded beams and unconservative for beams carrying heavy partitions or subjected to significant long-term effects such as creep and shrinkage. Experimental and analytical studies have reported that long-term deflection can be two to three times the short-term deflection because of creep, and that compression reinforcement reduces this effect. Authors have recommended explicit deflection

calculation for long spans, cantilevers, and beams supporting brittle finishes, which is made practical today by analysis software that reports elastic deflection directly.

The effect of beam stiffness on the distribution of moments in continuous frames has been examined in several analytical studies. In an indeterminate frame, the moments at beam-column joints are shared between the beams and columns in proportion to their relative stiffness. When beam depth increases, the beams become stiffer relative to the columns, and a larger share of the joint moment is carried by the beams, increasing the hogging moments at supports and reducing the column moments. Conversely, very flexible beams transfer more moment to the columns. Researchers modelling multi-storey frames in STAAD.Pro and ETABS have reported that support moments in beams may increase by 10 to 20 percent as the beam depth increases over the practical range, while mid-span sagging moments decrease slightly. These studies have also noted that the increase in self-weight of deeper beams adds to the moments, so that the net change is moderate.

Research on the role of beams in lateral load resistance has shown that beam stiffness strongly influences the lateral stiffness of moment-resisting frames. In a frame with flexible beams, the columns behave more like cantilevers, and lateral displacement is large. As the beams become stiffer, the frame approaches shear-type behaviour, in which the columns are restrained against rotation at each floor and lateral displacement is reduced. Studies of this effect for seismic design have also emphasised the strong-column weak-beam principle of IS 13920:2016, which requires the moment capacity of columns at a joint to exceed that of the beams by a margin. Very deep beams may make this requirement difficult to satisfy, so researchers have cautioned that beam depth should be increased only as far as necessary for deflection and strength.

Economic studies of beam sizing have compared the cost of concrete, steel, and formwork for beams of different proportions. Researchers have found that for a given moment, increasing the depth reduces the required tensile steel approximately in inverse proportion to the lever arm, while the concrete volume increases in proportion to the depth. The minimum cost section therefore lies at an intermediate depth, which several studies place at a span-to-depth ratio of about 10 to 14 for typical building beams. Authors have also considered the indirect cost of increased storey height and the architectural preference for shallow beams, and some have proposed optimisation procedures that minimise total cost subject to strength and serviceability constraints. The present study adopts a simpler comparative approach, analysing five practical beam sizes under identical conditions and comparing deflection, bending moment, and reinforcement to identify a suitable size.

III. SYSTEM ANALYSIS

The structural problem studied is the influence of beam cross-section on the bending moment, shear force, deflection, and reinforcement of beams in a multi-storey RCC frame. A G+4 residential building with a plan of 18 m by 12 m, bays of 6 m in both directions, and storey height of 3 m is taken as the case study. Columns are 400 mm by 400 mm and slabs are 125 mm thick, with M25 concrete and Fe500 steel throughout. Five beam sections are compared: B1 of 230 mm by 380 mm, B2 of 230 mm by 450 mm, B3 of 300 mm by 450 mm, B4 of 300 mm by 525 mm, and B5 of 300 mm by 600 mm. Dead load includes self-weight, floor finish of 1.0 kN/m², and wall load of 12 kN/m on beams, and live load is taken as 2 kN/m² according to IS 875 (Part 2). Seismic load corresponds to Zone II on medium soil. The parameters studied

are sagging and hogging moments, shear force, mid-span deflection, lateral displacement, and reinforcement for each beam size.

Existing System

In conventional practice, beam sizes are fixed at the start of design using thumb rules, such as a depth of span divided by 10 to 12 and a width equal to the wall thickness. Once selected, the same size is generally used for all beams of similar span without further comparison. Bending moments are often obtained from moment coefficients given in IS 456:2000 for continuous beams or from substitute frame analysis, which do not account for the actual stiffness of the columns and beams in a three-dimensional frame. Deflection is checked only through the span-to-effective-depth ratio, and actual deflection values are seldom calculated because the effective moment of inertia method is laborious by hand. The effect of beam size on lateral stiffness and on moments transferred to columns is usually ignored. When a beam fails the deflection check, the depth is increased by trial, and the design is repeated. This approach is quick for routine work but does not show clearly how deflection, moment, and reinforcement change with beam size.

Disadvantages of Existing System

- Beam sizes are fixed by thumb rules without comparing alternatives.
- Moment coefficients ignore the actual stiffness of beams and columns in the frame.
- Actual deflection values are rarely calculated during routine design.
- The span-to-depth check alone may not reveal problems for heavily loaded beams.
- The redistribution of joint moments with changing beam stiffness is not studied.
- The effect of beam size on lateral displacement of the frame is ignored.
- Revising beam sizes requires repeating the entire analysis by hand.
- Reinforcement quantities for different sizes are not compared systematically.
- Increase in self-weight with beam depth is not considered in comparisons.
- Results for different sizes are not presented together graphically.

Proposed System

The proposed approach uses STAAD.Pro to model the G+4 building as a three-dimensional frame and analyse it with five different beam sizes. Beams and columns are modelled as frame members with their actual section properties, slabs are represented through floor load distribution to the beams, and supports are fixed at the foundation level. Dead, floor finish, wall, and live loads are applied according to IS 875 (Parts 1 and 2), and seismic loads are applied according to IS 1893 (Part 1):2016 for Zone II. Load combinations for the limit state of collapse and the limit state of serviceability are generated according to IS 456:2000. For each beam size, the model is analysed and the bending moment and shear force diagrams, member deflections, and nodal displacements are obtained. The concrete design module designs the beams according to IS 456:2000, reporting the required tension and compression steel and shear reinforcement. The elastic mid-span deflection from the serviceability combination is compared with the limit of span divided by 250 and with the span-to-depth check, and all results are compared across the five sizes.

Advantages of Proposed System

- Bending moments reflect the actual relative stiffness of beams and columns.
- Deflection of every beam is obtained directly from the analysis.

- Changing the beam size requires only a change of section property.
- Hogging and sagging moments are available along the full length of each beam.
- The effect of beam size on lateral displacement is captured automatically.
- Self-weight changes with beam size are included in the analysis.
- Reinforcement for each size is designed to IS 456:2000 in the same run.
- Serviceability and strength combinations are evaluated consistently.
- Bending moment and deflection diagrams allow clear visual comparison.
- A suitable beam size can be selected on the basis of quantitative results.

IV. METHODOLOGY

The methodology begins with the preparation of the building plan and the fixing of bay dimensions, storey height, column sizes, and slab thickness. The structural model is created in STAAD.Pro by generating nodes and members, and the first beam size B1 is assigned to all beams along with the column properties. Materials for M25 concrete and Fe500 steel are defined, and fixed supports are assigned at the base. Self-weight, floor finish, and live load are applied as floor loads distributed to the beams, and wall loads are applied as uniformly distributed member loads, all according to IS 875 (Parts 1 and 2). Seismic loads are defined for Zone II according to IS 1893 (Part 1):2016. Load combinations for collapse and serviceability are created according to IS 456:2000. The model is analysed, and the maximum sagging and hogging moments, shear forces, mid-span deflections, and storey displacements are recorded for a selected interior and exterior beam. Beam design is performed to obtain reinforcement. The beam section is then changed to B2, B3, B4, and B5 in turn and the procedure repeated, after which the results are tabulated and plotted.

SYSTEM ARCHITECTURE

The workflow of the study follows a sequence of stages from data preparation to comparison. The Data Collection stage fixes the plan, spans, storey heights, and loading. The Geometry Modelling stage creates the G+4 frame in STAAD.Pro. The Section Definition stage defines the five beam sizes B1 to B5 along with fixed column and slab properties. The Material and Support stage assigns M25 concrete, Fe500 steel, and fixed supports. The Load Definition stage applies dead, live, and wall loads according to IS 875 and seismic loads according to IS 1893 (Part 1):2016. The Load Combination stage creates the limit state combinations of IS 456:2000. The Analysis stage solves the model for each beam size and extracts moments, shears, and deflections. The Design stage computes reinforcement and checks span-to-depth ratios according to IS 456:2000. The Result Comparison stage compares deflection, bending moment, lateral displacement, and steel for all five sizes and identifies the most suitable beam.

Comparison of Different Beam Sizes Based on Deflection and Bending Moment

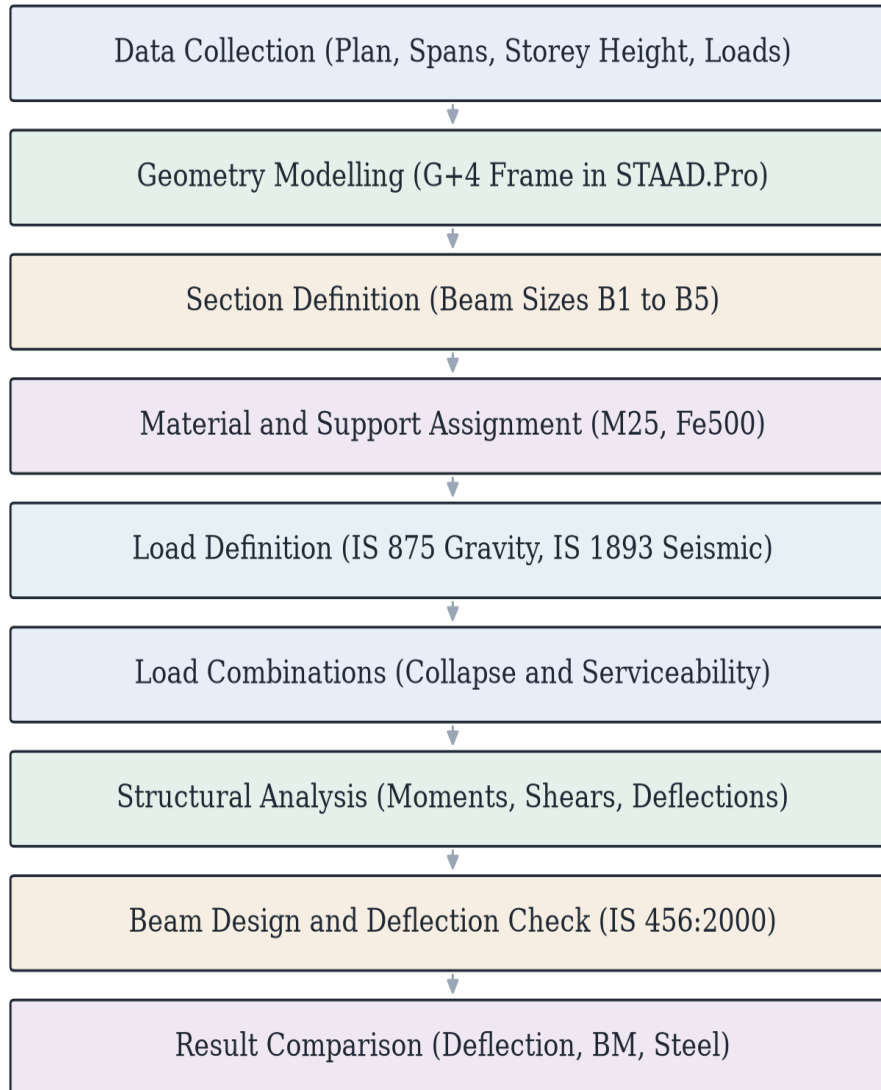
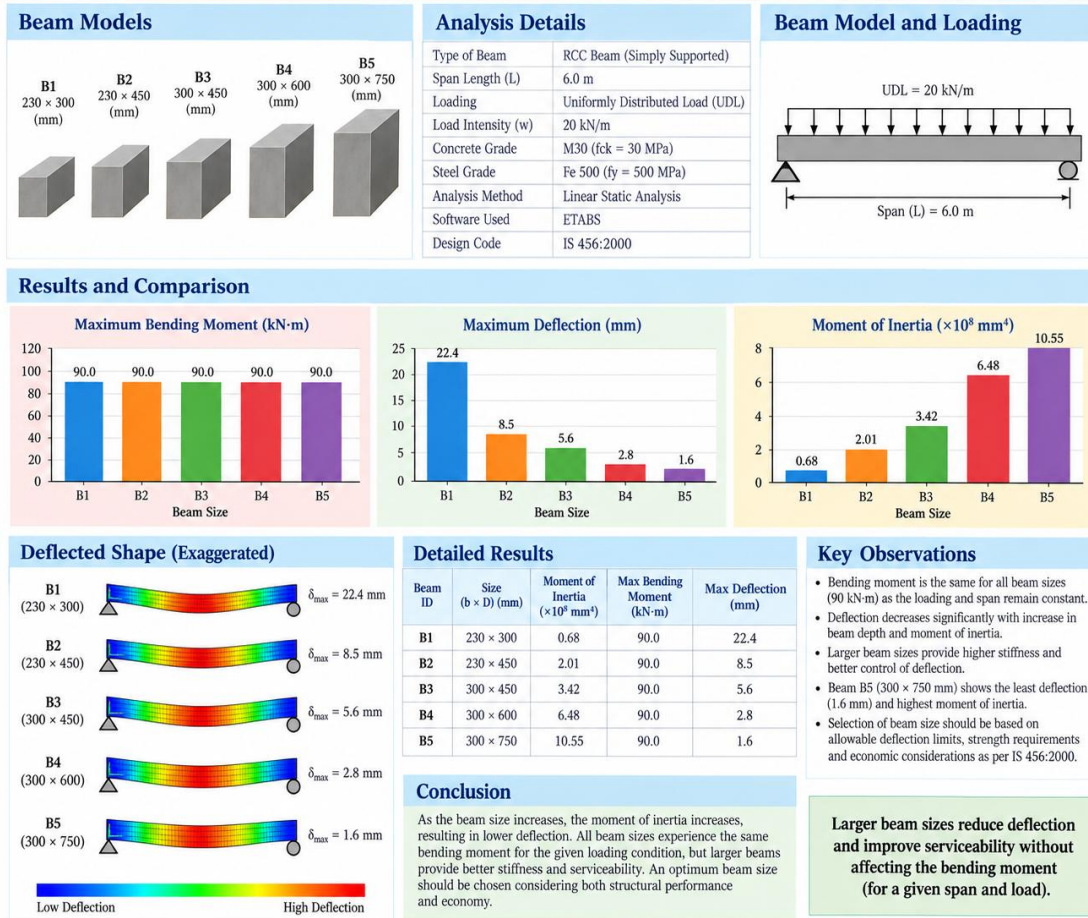


Fig. 1 System Architecture

V. RESULT AND OUTPUT

Comparison of Different Beam Sizes Based on Deflection and Bending Moment



VI. CONCLUSION

This study compared five beam sizes in a G+4 RCC framed building using STAAD.Pro, with all other parameters kept the same. Loads were applied according to IS 875 (Parts 1 and 2) and IS 1893 (Part 1):2016, and the beams were designed according to IS 456:2000. The comparison was made on the basis of bending moment, shear force, mid-span deflection, lateral displacement, and required reinforcement.

Deflection was found to be the parameter most sensitive to beam size. As the depth increased from 380 mm to 600 mm, the mid-span deflection of the typical 6 m beam decreased sharply, in close agreement with the inverse cube relationship between deflection and depth. Increasing the width from 230 mm to 300 mm at the same depth reduced deflection much less. All sizes satisfied the elastic deflection limit of span divided by 250, but the smallest section B1 did not satisfy the span-to-effective-depth check of IS 456:2000 without additional tension steel.

Bending moments changed moderately with beam size. Hogging moments at supports increased as the beams became stiffer, because a larger share of the joint moment was attracted by the beams, and the increase in self-weight added further to the moments. Sagging moments at mid-span changed only slightly. Despite the higher moments, deeper beams required less tensile reinforcement because of the larger lever arm, and the shallow sections B1 and B2 required steel close to the limiting percentage. Lateral displacement of the frame also decreased as beam stiffness increased.

For the span and loading considered, section B3 of 300 mm by 450 mm or B4 of 300 mm by 525 mm gave a balanced solution with acceptable deflection and moderate steel. Future work may include long-term deflection due to creep and shrinkage, cracked section properties, different span lengths, flanged beam action with the slab, and cost optimisation that includes formwork and storey height.

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