

COMPARATIVE STUDY OF DIFFERENT CONCRETE GRADES IN RCC BUILDINGS

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ABSTRACT

The grade of concrete is one of the first decisions made in the design of a reinforced concrete building, and it influences member sizes, reinforcement quantity, stiffness, durability, and cost. IS 456:2000 prescribes a minimum grade of M20 for reinforced concrete in mild exposure and higher grades for more severe exposure conditions. In practice, many designers continue to use M20 or M25 throughout a building without examining whether a higher grade could give a more economical or better-performing structure. The present study compares the structural behaviour and material requirement of an RCC building designed with different concrete grades.

A G+9 storey residential RCC framed building with a plan of 24 m by 18 m is modelled in STAAD.Pro. Four versions of the model are prepared with concrete grades M20, M25, M30, and M40, keeping the geometry, loading, and reinforcement grade of Fe500 the same. The modulus of elasticity of each grade is taken as 5000 times the square root of the characteristic compressive strength, as given in IS 456:2000. Dead and live loads are applied according to IS 875 (Parts 1 and 2), and seismic loads are applied for Zone III according to IS 1893 (Part 1):2016.

The four models are analysed under limit state load combinations, and the results are compared in terms of storey displacement, storey drift, fundamental time period, base shear, axial force and bending moment in critical columns and beams, and the reinforcement required. The concrete frame design module is used to design all beams and columns according to IS 456:2000, and in a second stage the column sizes are reduced where the higher grades permit, so that the saving in concrete volume and floor area can be assessed.

The results show that increasing the grade of concrete increases the stiffness of the frame, which reduces lateral displacement and drift and slightly shortens the natural period. Because the seismic weight is nearly unchanged, base shear increases only marginally with the grade. Column reinforcement reduces considerably as the grade increases, while beam reinforcement changes much less because flexural capacity depends mainly on the steel. When column sizes are optimised, the M30 and M40 models give smaller columns and a lower total material cost than the M20 model.

The study concludes that the choice of concrete grade should be made on the basis of structural performance and overall cost rather than the unit price of concrete alone. For multi-storey buildings, higher grades are particularly beneficial in the columns of the lower storeys, and a combination of grades over the height of the building may offer the best balance between economy, durability, and constructability.

I. INTRODUCTION

Concrete is the most widely used construction material in the world, and its properties can be adjusted over a wide range by changing the proportions of cement, aggregates, water, and admixtures. The grade of concrete denotes its characteristic compressive strength at 28 days, and in India it is specified as M20, M25, M30, and so on, where

the number is the strength in newtons per square millimetre. Advances in cement chemistry, mineral admixtures, and superplasticisers have made grades of M40 and above readily achievable at ready-mix plants in most cities.

The grade of concrete affects nearly every aspect of the structural behaviour of a building. Higher strength allows columns to carry larger axial loads with smaller cross sections, and a higher modulus of elasticity makes the frame stiffer, which reduces deflection and lateral drift. Higher grade concrete also usually has lower permeability and better resistance to carbonation and chloride penetration, which improves durability. On the other hand, the unit cost of concrete increases with its grade, and higher grades require stricter quality control during mixing, placing, and curing.

IS 456:2000 links the minimum grade of concrete to the exposure condition, requiring M20 for mild exposure, M25 for moderate, M30 for severe, M35 for very severe, and M40 for extreme exposure. Beyond this durability requirement, the grade is chosen by the designer. Many small and medium buildings are still designed with M20 or M25 in all members out of habit, while designers of tall buildings often use M40 or M50 in the lower columns. There is therefore a practical need to compare the effect of different grades on a typical multi-storey building in a systematic way.

The present work carries out such a comparison for a G+9 residential building modelled in STAAD.Pro. The same building is analysed and designed with M20, M25, M30, and M40 concrete, and the displacement, drift, member forces, reinforcement, and material quantities are compared. The aim is to identify the grade that gives the most favourable combination of structural performance and economy for this class of building, and to show how software analysis can support such a decision at the design stage.

II. LITERATURE SURVEY

The influence of concrete strength on the behaviour of reinforced concrete members has been studied extensively through experiments and analytical models. Early research established the relationship between compressive strength and other properties such as tensile strength, modulus of elasticity, and bond strength with reinforcement. Design codes, including IS 456:2000, express the modulus of elasticity as proportional to the square root of the characteristic strength, so that an increase in grade from M20 to M40 increases the modulus by about 41 percent. Researchers have noted that this relationship is approximate and that the actual modulus depends on the type and proportion of aggregate, but it is adequate for design analysis. Experimental studies on columns have shown that the axial load capacity increases almost linearly with the concrete strength, while studies on beams have shown that the flexural capacity of under-reinforced sections is governed mainly by the steel and increases only slightly with concrete grade. These findings explain why the benefit of higher grades is felt mainly in compression members.

Several parametric studies have compared the performance of multi-storey RCC buildings designed with different concrete grades using commercial analysis programs. Investigators working with STAAD.Pro and ETABS have modelled buildings of eight to twenty storeys with grades ranging from M20 to M50 and reported that lateral displacement under wind and seismic loading decreases steadily as the grade increases, because of the increase in frame stiffness. The reduction in top storey displacement from M20 to M40 has typically been reported in the range of 15 to 25 percent for the same member sizes. The natural period also decreases, which in some cases increases the spectral acceleration and therefore the base shear slightly.

Authors have emphasised that the benefit in drift is most useful for tall and flexible buildings in which drift, rather than strength, governs member sizes.

The economic aspect of concrete grade selection has been examined by researchers who prepared quantity estimates and cost comparisons for buildings designed with different grades. These studies generally report that if member sizes are kept constant, higher grades increase the total cost because the concrete becomes more expensive while the saving in steel is limited. When column sizes are reduced to take advantage of the higher strength, however, the saving in concrete volume, reinforcement, formwork, and self-weight can outweigh the higher unit price. Several authors have also pointed out the indirect benefit of smaller columns in the form of increased usable floor area, which is valuable in commercial and residential buildings where the carpet area determines the revenue. The general conclusion of these studies is that higher grades become economical above a certain building height, and that this height depends on local material prices and the loading on the structure.

Durability considerations have received increasing attention in recent research on concrete grade selection. Studies on the deterioration of reinforced concrete buildings in coastal and industrial environments in India have found that many structures built with low grade concrete and inadequate cover show corrosion of reinforcement within twenty to thirty years. Researchers have related this to the higher permeability and faster carbonation of low strength concrete with a high water-cement ratio. IS 456:2000 responded to these observations by increasing the minimum grade and cover requirements for different exposure conditions and by limiting the maximum water-cement ratio. Authors have recommended that the grade of concrete be selected not only for strength but also for the expected service life, and that life-cycle cost, including repair and maintenance, be considered when comparing alternatives.

Research on the use of different grades within the same building has explored the idea of assigning higher grades to heavily loaded columns and lower grades to beams and slabs. Studies have examined the practical difficulty of placing different grades at beam-column junctions and have discussed the provisions of design codes that address this issue, such as limiting the difference in strength between column and floor concrete or requiring the higher grade to be placed around the column in the floor. Analytical studies have shown that using M40 or M50 in the lower storey columns and M25 or M30 in beams and slabs can reduce column sizes significantly while keeping the floor system economical. Other studies have compared high performance concrete with conventional grades and found benefits in stiffness, creep, and shrinkage. The present study builds on this body of work by comparing four grades for a typical G+9 building under identical conditions and by examining both performance and material quantities.

III. SYSTEM ANALYSIS

The structural problem considered is the effect of concrete grade on the analysis results, design, and material requirement of a multi-storey RCC framed building. A G+9 residential building with a plan of 24 m by 18 m, bay spacing of 6 m in both directions, and storey height of 3.2 m is taken for the study. Initial member sizes are columns of 500 mm by 500 mm, beams of 300 mm by 500 mm, and slabs of 150 mm thickness. Four models are prepared with M20, M25, M30, and M40 concrete, all with Fe500 reinforcement. Dead load includes self-weight, floor finish of 1.5 kN/m², and wall load of 13.8 kN/m on external beams and 6.9 kN/m on internal beams. Live load of 2 kN/m² is taken for residential floors and 1.5 kN/m² for the roof according to

IS 875 (Part 2). Seismic load is applied for Zone III on medium soil with an importance factor of 1.0 and a response reduction factor of 5. The parameters studied are displacement, drift, time period, base shear, member forces, reinforcement, and cost.

Existing System

In conventional design practice for residential and commercial buildings of moderate height, the concrete grade is usually fixed at the outset on the basis of habit, local availability, or the minimum grade required by IS 456:2000 for the exposure condition, and the same grade is used for all members. Member sizes are selected from thumb rules and previous projects, and the frame is analysed once for that grade. Alternative grades are rarely examined because each alternative would require the analysis, design, and quantity estimation to be repeated. When hand calculation or simple two-dimensional analysis is used, the effect of the modulus of elasticity on lateral stiffness is often ignored, so that the benefit of a higher grade in controlling drift is not seen. Cost comparisons, when made at all, usually consider only the unit price of concrete and do not include the change in reinforcement, formwork, self-weight, and usable floor area. As a result, the chosen grade may not give the most economical or durable structure for the building under consideration.

Disadvantages of Existing System

- Concrete grade is fixed by habit rather than by comparison of alternatives.
- The same grade is used in all members regardless of the forces they carry.
- The effect of grade on frame stiffness and lateral drift is often neglected.
- Repeating manual analysis and design for several grades is time-consuming.
- Cost comparison considers only the unit rate of concrete and ignores other items.
- Savings in column size and floor area from higher grades are not evaluated.
- Durability requirements beyond the minimum code grade are rarely considered.
- Column reinforcement percentages near the upper limit go unnoticed until detailing.
- Quantities of concrete and steel must be estimated separately after design.
- Results for different grades are not presented together for easy comparison.

Proposed System

The proposed approach uses STAAD.Pro to analyse and design four otherwise identical models of the G+9 building with M20, M25, M30, and M40 concrete. The geometry is created once, and material properties are changed for each model, including the characteristic strength and modulus of elasticity computed from IS 456:2000. Gravity loads are assigned according to IS 875 (Parts 1 and 2), and seismic loads are generated through the IS 1893 (Part 1):2016 seismic definition with the mass source taken as dead load plus the appropriate fraction of live load. Load combinations for limit state design are generated automatically. Each model is analysed, and displacement, drift, time period, base shear, and member forces are extracted. Concrete design to IS 456:2000 is performed for all beams and columns, giving the required reinforcement. In a second stage, column sizes in the higher grade models are reduced to the smallest section that satisfies strength and drift requirements, and the models are re-analysed. Quantities of concrete and steel are extracted from the software and combined with current unit rates to compare cost.

Advantages of Proposed System

- The effect of concrete grade is isolated by keeping all other parameters constant.
- Modulus of elasticity is updated automatically, so stiffness effects are captured.
- Displacement and drift for each grade are obtained at every storey level.
- Reinforcement for all beams and columns is designed to IS 456:2000 in a single run.
- Column sizes can be optimised for higher grades and checked quickly.
- Material quantities are obtained directly from the analysis model.
- Cost comparison includes concrete, steel, and the effect of reduced member sizes.
- Load combinations of IS 456 and IS 1893 are applied consistently to every model.
- Results for the four grades can be tabulated and plotted side by side.
- The same procedure can be extended to mixed grades over the building height.

IV. METHODOLOGY

The methodology begins with the preparation of the architectural plan and the fixing of bay sizes, storey heights, and preliminary member dimensions. The structural geometry is generated in STAAD.Pro, and beams, columns, and slabs are assigned their section properties. Four material definitions are created for M20, M25, M30, and M40 with the corresponding modulus of elasticity, density, and Poisson ratio, and the first model is assigned M20. Supports are fixed at the foundation level. Dead load, floor finish, wall loads, and live loads are applied according to IS 875 (Parts 1 and 2), and the seismic definition for Zone III is specified according to IS 1893 (Part 1):2016. Seismic load cases in both horizontal directions and limit state load combinations are created, and the model is analysed. Storey displacement, drift, base shear, and member forces are recorded, and concrete design is performed to IS 456:2000. The model is then copied and the material changed to M25, M30, and M40 in turn, with the analysis and design repeated. Column sizes are optimised for the higher grades, quantities are extracted, and costs are compared.

SYSTEM ARCHITECTURE

The workflow of the study consists of a series of stages that lead from basic building data to a comparison of grades. The Data Collection stage defines the plan dimensions, storey heights, occupancy, and site seismic parameters. The Geometry Modelling stage creates the three-dimensional frame with beams, columns, and slabs in STAAD.Pro. The Material Definition stage creates the four concrete grades with their strength and modulus of elasticity according to IS 456:2000. The Load Definition stage applies dead and live loads according to IS 875 and seismic loads according to IS 1893 (Part 1):2016. The Load Combination stage generates the limit state combinations. The Analysis stage solves each model and extracts displacement, drift, period, and member forces. The Design stage designs beams and columns to IS 456:2000 and reports reinforcement. The Optimisation stage reduces column sizes where the higher grades permit, and the Quantity and Cost Comparison stage combines material quantities with unit rates to identify the most suitable grade.

Comparative Study of Different Concrete Grades in RCC Buildings

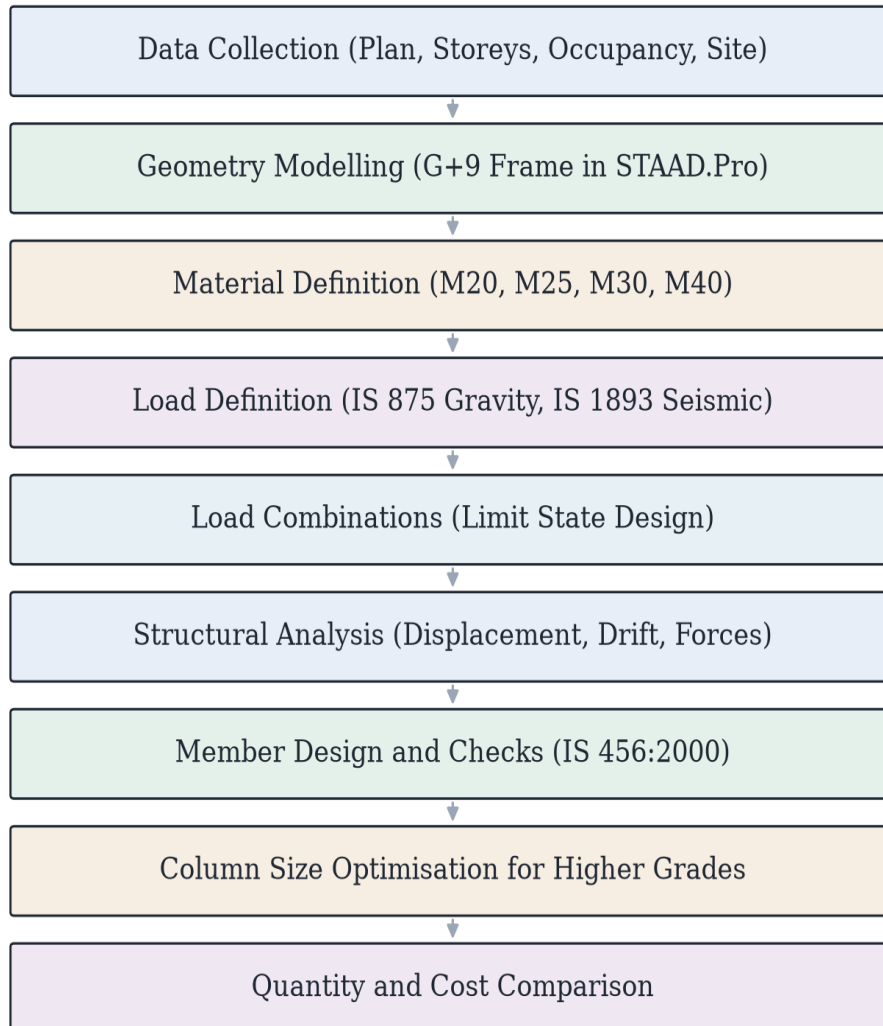
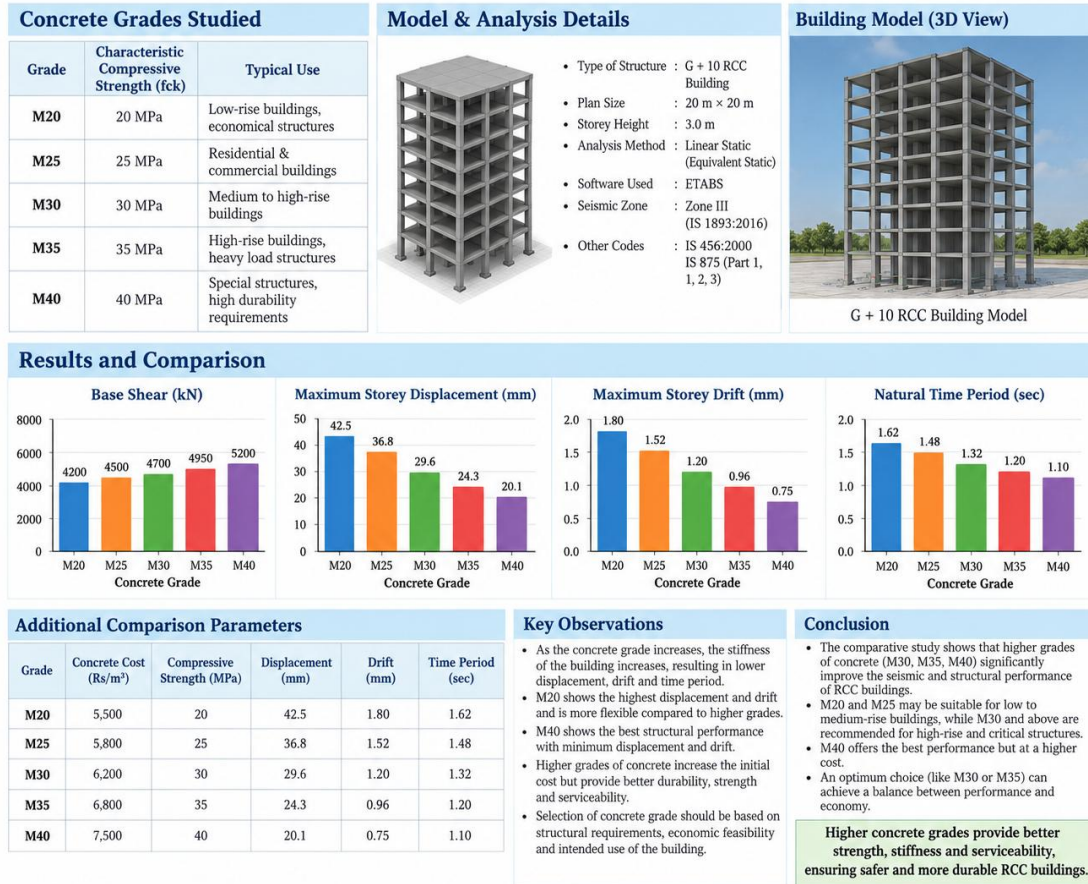


Fig. 1 System Architecture

V. RESULT AND OUTPUT

COMPARATIVE STUDY OF DIFFERENT CONCRETE GRADES IN RCC BUILDINGS

Analysis of Structural Performance, Cost and Serviceability



VI. CONCLUSION

This study compared the structural performance and material requirement of a G+9 RCC residential building designed with M20, M25, M30, and M40 concrete using STAAD.Pro. The geometry, loading, and reinforcement grade were kept the same in all models, so that the effect of concrete grade could be observed clearly. Gravity loads were applied according to IS 875 (Parts 1 and 2), seismic loads for Zone III according to IS 1893 (Part 1):2016, and all members were designed according to IS 456:2000.

Increasing the grade of concrete increased the modulus of elasticity and therefore the lateral stiffness of the frame. The maximum top storey displacement and inter-storey drift decreased steadily from M20 to M40, with the drift reduced by nearly one fifth, and all models remained within the drift limit of 0.004 times the storey height. The fundamental period reduced slightly with increasing grade, and the base shear increased marginally because of the higher spectral acceleration corresponding to the shorter period.

The largest effect of concrete grade was observed in the columns. For the same column sizes, the required longitudinal reinforcement in the ground storey columns reduced significantly as the grade increased, and several columns that needed close to the maximum practical steel percentage with M20 required only moderate steel with M40. Beam reinforcement changed much less, since the flexural capacity of under-

reinforced beams depends mainly on the steel. When column sizes were reduced for the higher grades, the M30 model gave the lowest overall cost of concrete and steel, while the M40 model gave the smallest columns and the largest gain in usable floor area.

The study indicates that for buildings of ten storeys or more, grades of M30 and above deserve serious consideration, particularly for columns in the lower storeys. Future work may examine mixed grades over the height of the building, include the effect of creep and shrinkage on long-term deflection, consider wind loading for taller buildings, and extend the cost comparison to a life-cycle basis that accounts for durability and maintenance.

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