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Structural Design of Multi-story Residential Building for in Salem , India

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INTRODUCTION

The structural analysis and design aspects of a four story reinforced – concrete building, designed and built in Salem, Tamilnadu State, India, is described herein. The design was referred to the second author for proof checking. The building is an apartment complex proposed by the Tamil Nadu Housing Board . This is a reinforced concrete framed building. This was done at the PSG College of Technology, Coimbatore, India, as a part of senior thesis design at WPI, in Worcester MA, 01609 at the India Project Centre at PSG College of Technology, Coimbatore, India, for a period of 7 weeks as a residential student project. The students names are Frederic Carrie, Abraham Pinales and Antonio Durate. This was accomplished as their project centre in PSG College of Technology, Coimbatore, India, during the year 1998. This was part of the degree requirements for BSCE in Civil and Environmental Engineering at WPI. WPI sent 20 students to the India Projects program at PSG College of Technology, Coimbatore, under the sponsorship of Dr. S. Rajasekaran, Chair, CEE Department at PSG College of Technology. Professor S. Rajasekaran served as the on campus advisor, while Professor P. Jayachandran, served as an off-campus advisor at WPI.

The students did a literature survey, problem definition and did a complete structural analysis and design of the four story residential building in reinforced concrete. They followed the Indian code BIS 456 – 1978 and used ACI-1999 and wind/earthquake loads by using Canadian Code 1995, and ANSI standards 1995 for checking. The analysis and design of slabs, beams, girders, columns and footings were completed using theory from Reinforced Concrete Design and Structural Analysis by STAAD-III software, which uses finite elements. Design for slabs, beams , columns and footings were carried out using the software RC Design Suite. Drawings were done using Auto-CAD. To prevent the misuse of these software applications, the Limit State Design was exclusively used as a hand calculation method to verify the output from STAAD-III and RC Design suite.

Estimating and quantity surveying was done to calculate quantities and specifications for construction and fabrication. The drift was kept to within H/500, where theory for design adapted was, from textbooks by C.K. Wang and C.G. Salmon in Reinforced Concrete Design and J.G.McGrager, Reinforced Concrete Design, and S.Rajasekaran, Finite Element Method.

The students have completed structural design and drawings and a technical report and made a presentation of results, before an audience of Senior Professors and other faculty members and students of PSG College of Technology as well as at WPI. This project was awarded a Provost's Award at WPI. WPI will be sending a group of students to PSG Tech in 2006. This is being examined at WPI.

DESIGN SPECIFICATIONS

The three dimensional view of the building is shown in Fig.1 and the plan view is given in Fig.2. The geometrical properties of the structure included a maximum length spanning 48.27 meters, and a maximum width of 31.60 meters. The building comprised of 2.9 meter floors and spanned 11.6 meters above grade. A wall beam was provided 0.75 meters below grade to support the earth pressure against supporting columns above the footings of the structure. At the roof level, a mechanical room was provided for the elevator of the complex. (1metre = 3.281 feet)

Each typical floor consisted of 8 apartments. The slab of the bath room was depressed approximately 0.6 meters and was accounted for in the beam design around the toilet rooms. A balcony was attached to each apartment, and the loading was accounted for in the floor beam design . The Indian code BIS 456- 1978 was used using the concrete mix with 15 MPa and 415 MPa reinforcing steel. The surrounding conditions indicated a low – seismic, and a strong soil layer boundary with a strength of 150 KN/sq.m. As indicated, the height to width ratio of the structure did not exceed 2, therefore a wind analysis was not required according to the Indian Code. Due to the monsoon season, the Indian Code included a specific loading for the roof of the structure.

ASSUMPTIONS MADE

1. Only centre line dimensions are taken
2. The base joints are assumed to be hinged and assumed to be at a depth of 3.35 m below ground level.
3. Half of the structure is considered because of symmetry and on the symmetric axis suitable boundary conditions are applied
4. Even though the beam behaviour is like a T beam over a certain length of span, moment of inertia is calculated based on the rectangular beam. This is on the conservative side.
5. The following three loading conditions are considered a) dead load b) live load c) 1.5 dead load + 1.5 live load. Since the design is carried out using limit state design load factor of 1.5 is used.
6. The live load on the slab is assumed as 3 kN/sq.m and the self –weight of slab + floor finish (assuming 120 mm thick) is taken as 4 kN/sq.m and the total load on the slab is taken as 7 kN/sq.m for all floors except roof for which 10kN/sq.m is considered. Based on slab load and 45 degrees distribution the loads for beams for all floors are considered.
7. In addition, the wall load assuming the self-weight of masonry as 20 kN/cu.m is taken as 13.34 kN/m for full brick wall and 6.67 kN/m for half brick wall.
8. The slab is assumed to be 120mm thick , floor and roof beams are assumed as 230 x 450 mm or 230 x 400 mm as the case may be and the concrete columns are assumed

to be 230x380 and some columns are assumed to be 230 x 450 . The columns in the lift portion are assumed to be 230 x 230

9. The safe bearing capacity of the soil is taken as 150 kN/sq.m

ANALYSIS BY STAAD-III

Staad-III is a finite element analysis and design software system and was developed by Research Engineers Inc. In addition to the analysis and design complete graphical interface is included in this package. The following are the main options available from the concurrent Graphics environment.

STAAD-III - Analysis and Design
STAAD-III – Graphical Input Generator
STAAD-POST – Graphical post processing
STAAD-INTDES – Interactive Design of structural components

This package can perform static analysis, second order stability analysis and dynamic analysis. It uses 2 or 3 dimensional frame elements, grid elements, and continuum elements and spring elements. Extensive design capabilities are available in STAAD-III/ISDS for steel, concrete, timber and pre-stressed sections. Interactive design consists of design for footing, slab and retaining walls. One can also get deformed shape, bending and shear and axial forces diagrams. Displacements are also checked for ACI, Canadian and Indian Standards.

SIX STEPS IN THE ANALYSIS

The following six steps are used in the Finite element analysis of any structure.

1. Idealize the structure into a number of elements
2. Develop the element stiffness matrix using constitutive law.
3. Assemble the element stiffness to form global stiffness matrix using compatibility and equilibrium.
4. Apply necessary boundary conditions
5. Solve the equations [K]{r}={R} where [K] is the structural stiffness matrix, {r} – generalized displacements and {R} – generalized forces.
6. Knowing the displacements solve for elemental stresses.

The four story-building complex included a 3 dimensional mesh arrangement consisting of 2212 nodes with total of 6 degrees of freedom at each node. This model required a total of 13272 equilibrium equations to be solved in the form of a matrix system, ad in order to compute bending moments and displacements. Fortunately, the building contains a symmetry line, which permitted the analysis of half of the structure , therefore reducing the mesh arrangement to 1106 nodes and the number of equations was reduced to a total of 6636 equations which were solved using STAAD-III. The renumbering of nodes is automatically done so as to reduce the bandwidth. Reducing the number of equations and reducing the bandwidth of the matrix system to be solved, which alternatively required less time from cpu point of view. This factor is extremely important especially in the industry since most companies operate on a network basis, which could ultimately affect the daily productivity. It also reduces the chance of human error in the input file which consists of over 2500 lines of the code.

RC-DESIGN SUITE

RC –Design suite is a reinforced concrete design program that has numerous applications for the design of concrete structures. It contains modules for the design of beams, columns , footings and slabs. For this project the students utilized this program only for the design of floor slab and combined footings. This program will also be used in the partial design of the raft footing. Design of beams and columns are carried out in STAAD- III package itself. A clear cover of 20 mm is adopted for the slab. For each column load the individual footing is designed. However, many of these individual footings overlapped each other and had to be redesigned as combined footings. RC Design – suite provided an effective way of designing these combined footings through its footing design module. The footing design module of the program provides the footing length, effective depth and reinforcement requirements. The raft footing was designed in the area under the lift duct of the building. Some criteria dictated that the support to the elevator shaft should be watertight. RC-Design Suite was used to engineer the design of the raft. Four column loads of 562 kN, 425 kN, 832 kN and 498 kN are being transmitted to the four corners of the raft of the lift well. The design of the raft footing was modelled adopting an inverted slab-beam-column approach. To prevent deterioration in the footing, associated with the position of the water table, it was decided that a raft footing would be beneficiary since its depth would be considerably less than a conventional shallow or combined – footing. The thickness of the raft was 0.6 m .

IMPORTANCE OF HAND CALCULATIONS

The students have been asked to perform hand calculations. Computer analysis and design programs offer great benefits to the design engineer. However, the computer programs can be easily misused without proper precautions in analysis and design procedures. If the design of any structure is based on the results obtained from erroneous computer analysis, it can lead to structural failures, costly disputes and poor performing structures. Performing the following procedures can eliminate many of the errors.

1. Model the structure as closely to the real structure as possible.
2. Recognize the important structural reactions
3. Check the input and understand the material behaviour and boundary conditions
4. Perform simple equilibrium and compatibility checks using hand calculations.
5. Know and understand the limitations of the software.

A series of hand design calculations were performed on a typical slab panel, a randomly selected set of three beams and columns, one critical footing supporting the highest column load in the structure, and a typical combined footing. The purpose of the hand design calculation was to verify manually, the analysis from the finite element software package, STAAD-III and the Indian code driven RC Design Suite programs.

WHAT THE STUDENTS LEARNT IN THE MAJOR QUALIFYING PROJECT

1. To use Autocad to sketch the floor plan (see Fig.2) and the details of the frame and foundations of the structure and also the details of beam etc as shown in Fig.3
2. To use Microsoft EXCEL to facilitate the computation of the service loads on the structure.
3. To use STAAD-III package for the analysis of four storied apartment complex
4. To familiarize with Indian Code BIS 456- 1978 and other American and Canadian codes.
5. To use RC – Design Suite for the design of slabs and combined footings.

REFERENCES

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5. Carrie, F., Pinales, A. and Duarate, A., " Structural Analysis and Design of Multi-Story Building in Salem, India, Major Qualifying Project submitted for BSCE Degree, Worcester Polytechnic Institute, Worcester, MA., and PSG College of Technology, Coimbatore, India, 1998 - A Global Studies Project under IGSD of WPI.

ABSTRACT

The structural analysis and design of 4 story multistory building complex for the hostel for legislators of Tamil Nadu State in Salem, Tamil Nadu, in India, is described herein. This is a result of a senior thesis project completed by 3 senior students, Fred Carrie, Abraham Pinales and Antonio Duarte, of Worcester Polytechnic Institute, Worcester, Massachusetts, carried out at its India Project Centre, at PSG College of Technology, Coimbatore, India. Salem is a sister city of Salem, Massachusetts. Gravity and Lateral loads were determined using Canadian Code 1995, ANSI Standards 1995 and Indian Standards 1990. Stress analysis was conducted using finite elements, and utilizing STAAD3 software system. Structural design was accomplished for reinforced concrete slabs, beams, girders, columns and footings, based on this stress analysis an its resultants. Design drawings were prepared, and specifications written for construction. Dr.S.Rajasekaran, the second author was the structural consultant for proof checking of the building's design by its project structural engineers. The students' project verified some aspects of this peer review of design. Students traveled to India and did this project at PSG College of Technology, under the guidance of Profs. P. Jayachandran and S. Rajasekaran. WPI global studies division has sponsored this 7-week residential project in

India. The students have reported that this project was a life changing experience for them, as they learned about design in India, and its culture and its people.

BIOGRAPHICAL SKETCHES

Dr. P.Jayachandran is on the faculty of Civil and Environmental Engineering at WPI, Worcester, Massachusetts. He has design experience as Senior Engineer at CBM Engineers, Inc., Houston, TX, which has designed the tallest buildings in Los Angeles, Houston, Dallas, New Orleans, Washington, DC., and in St.Louis. He was also a Research Engineer in Structural Engineering Research Centre, Madras, India, a national laboratory. He has Ph.D from University of Wisconsin, Madison, WI. See www. sercm@nic.in and also www.wpi.edu

Dr.S.Rajasekaran is the Chair of Infrastructure Engineering and CEE at PSG College of Technology, Coimbatore, India. He is an expert in Non-linear FEM, and has recently carried out non-linear FEM based stress analysis, for the design of LCA-Light Combat Aircraft, for the ADA-Aeronautical Development Agency, Bangalore, India. PSG College of Technology is a top 10 school in India in Science and Technology. He has Ph.D from University of Alberta, Edmonton, Canada, and D.Sc. from Bharathiar University, India. See www.psgtech.edu

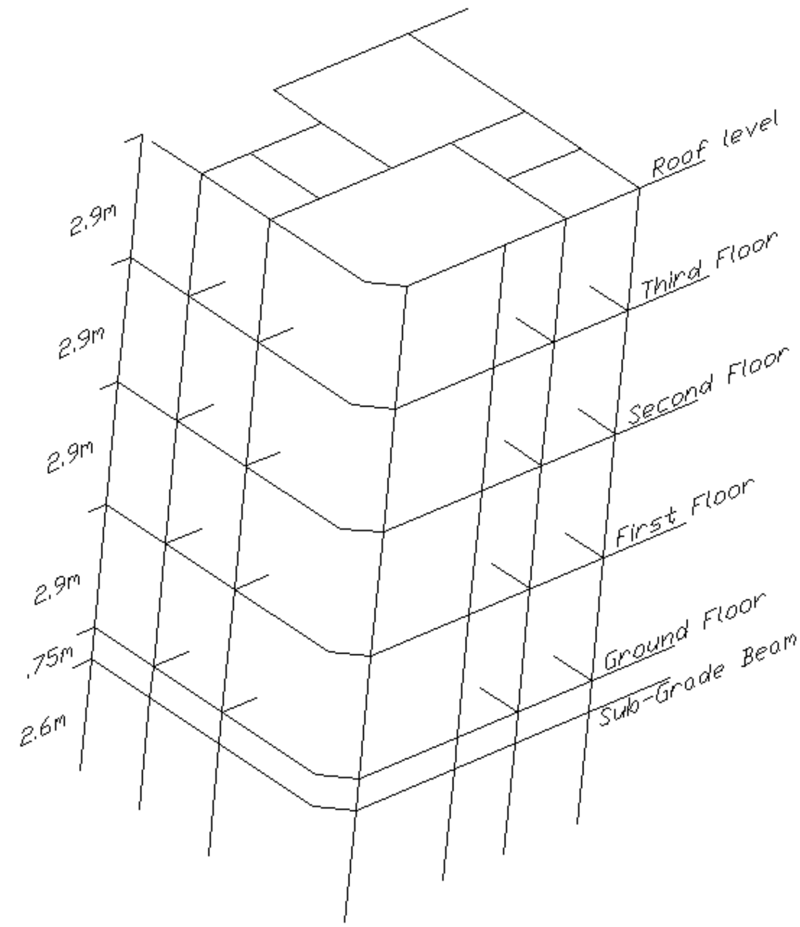
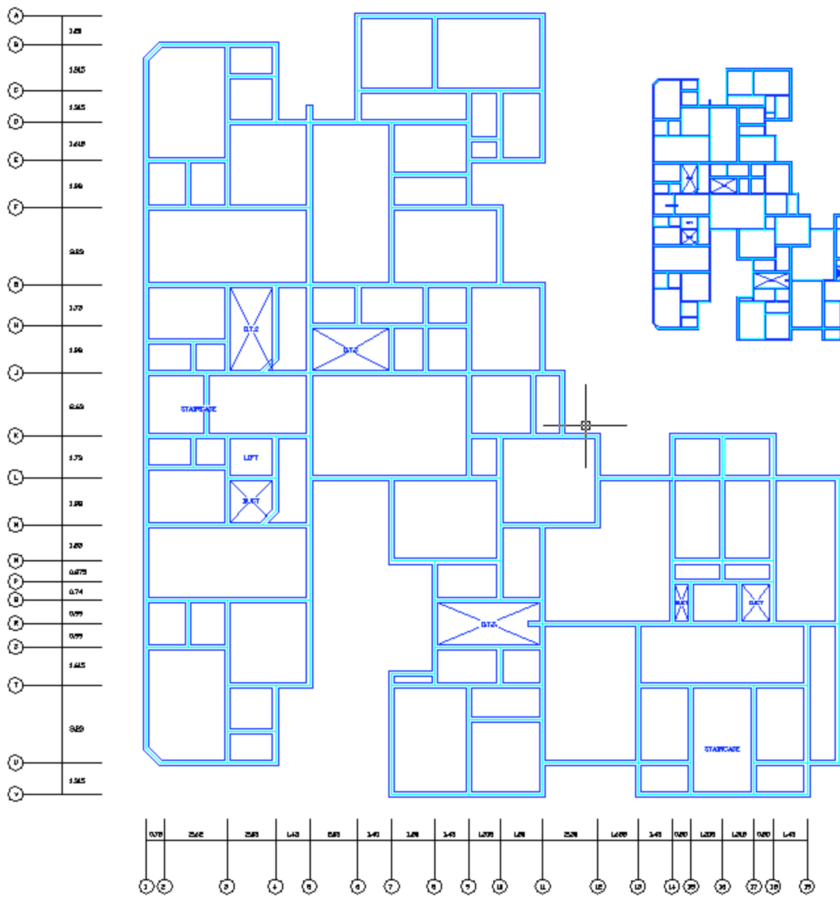


Figure 1-Three Dimensional View



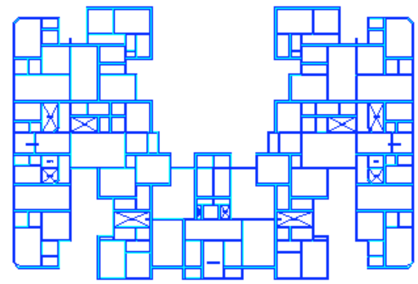


Figure 2-Typical Floor Plan

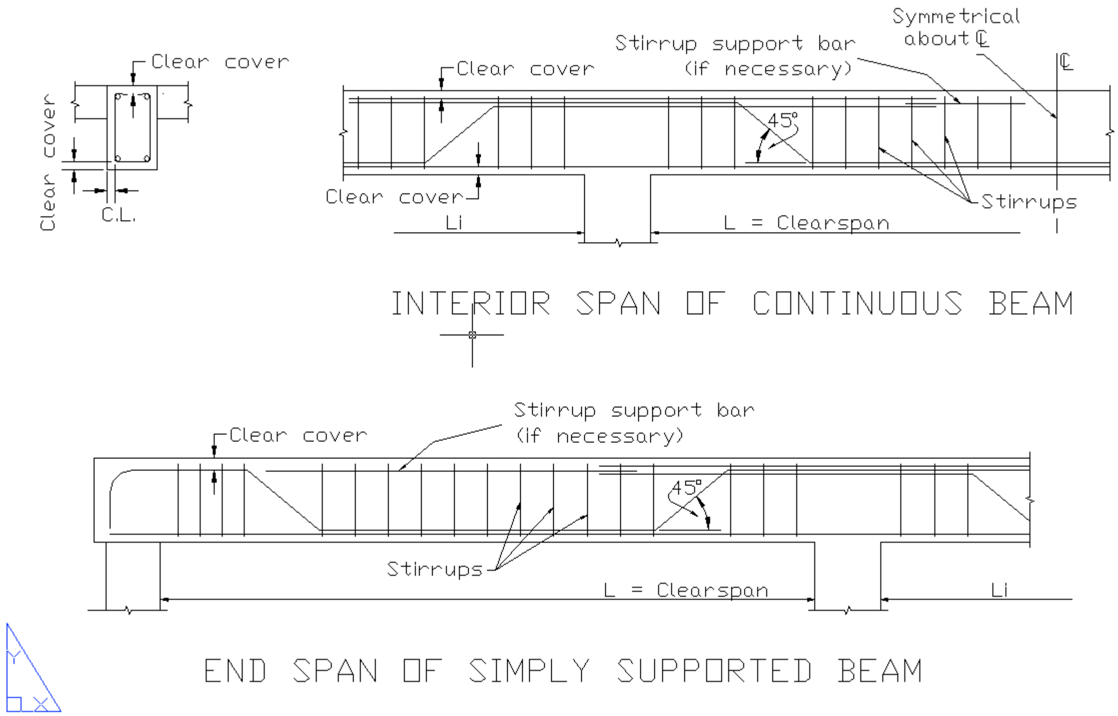


Figure 3-Typical Beam Design