Analysis and Design of Precast Load Bearing Walls for Multi-Storey Building

R. Uday Kukmar¹, P. Sai²
¹M.Tech (PG Scholar), Dept. of CE, AVR & SVR College of Engineering, Anantapur
²Assistant Professor, Dept. of CE, AVR & SVR College of Engineering, Anantapur

Abstract- In the present scenario of construction industry, time of construction is very crucial factor. Pre-cast construction is gaining significance in general and urban areas in particular. The precast technology is a viable and alternative technique to reduce the construction time. G+11 storey live project is taken for analysis and design with load bearing walls. Design of precast wall panels and design of precast slabs is carried using Indian codes subjected to gravity and lateral loads (seismic and wind). Connections of wall to wall, wall to slab and foundation beam to wall is designed. The structural system consists of load bearing walls and one-way slabs for gravity and lateral loads have been taken for analysis using ETABS. Various wall forces, displacements and moments have been worked out for different load combinations. Data base is presented for the worst load combination. Lateral load on a multistory building is most critical one to consider for the design. In order to observe the seismic effect and wind effect on multi-story building, a study on precast load bearing wall of G+11 has been carried out. Four different seismic zones and all wind zones are considered for analysis using ETABS. The structural response due to lateral loads with load combination is extracted. Effect of lateral load on out-of-plane moments, axial forces, shear force, base shear, maximum storey drift and tensile forces on shear wall are plotted. Finally the effect of seismic zone and wind zone is tabulated.

I. INTRODUCTION

Now days, there is an increase in housing requirement with increased population and urbanization. Therefore, building sector has gained increasing prominence. However, the fact that the suitable lands for building/construction- especially in the areas in which people live intensively- are limited and expensive shows that there is a necessity for optimal evaluation of these lands. Additionally, continuously increasing prices leads to increase in building costs; so, both dimensional and cost optimization becomes necessary and even indispensable. When a building is projected, geometrical dimensions of elements belonging to carrier system of the structure are usually determined by using engineering capability and experiences gained over time. In sizing, the tensile forces to which the material to be subjected to should comply with the specifications. In the building design, the pre-sizing details provided are generally not changed much; sizes obtained in second or – at most third solution are taken as carrier system sizes. In fact, carrier system can be sized in infinite possibilities in a manner to ensure all the necessary conditions; and the cost of each carrier system alternative can be different from each other. The basic aim in the engineering is to find a design having lowest cost, and ensuring predicted limitations.

Concrete structural walls provide cost effective mean stores ist seismic lateral loads and thus they are frequently used as the primary lateral load resisting system in reinforced concrete buildings. Structural walls with high flexural stiffness typically assist with limiting inter storey drifts in buildings, consequently reducing structural and non-structural damage during seismic events. Superior performance of buildings that consisted of structural walls was evident in several past seismic events. The concrete structural walls can be of cast-in-place concrete or of precast concrete. With the added benefits of prefabrication, precast walls make an excellent choice for resisting lateral loads in concrete buildings. However, the application of precast systems is generally limited in seismic regions due to the lack of research.
Precast concrete is a construction product produced by casting concrete in a reusable mold or “form” which is then cured in a controlled environment, transported to the construction site and lifted into place. In contrast, standard concrete is poured into site-specific forms and cured on site. Precast stone is distinguished from precast concrete by using a fine aggregate in the mixture, so the final product approaches the appearance of naturally occurring rock or stone.

There are many different types of precast concrete forming systems for architectural applications, differing in size, function, and cost. Precast architectural panels are also used to clad all or part of building facade free-standing walls used for landscaping, soundproofing, and security walls, and some can be Prestressed concrete structural elements. Storm water drainage, water and sewage pipes, and tunnels make use of precast concrete.

The concept of precast (also known as “prefabricated”) construction includes those buildings, where the majority of structural components are standardized and produced in plants in a location away from the building, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build a large number of buildings in a short time at low cost.

The main features of this construction process are as follows:

- The division and specialization of the human workforce
- The use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts and products
- Compared to site-cast concrete, precast concrete erection is faster and less affected by adverse weather conditions.
- Plant casting allows increased efficiency, high quality control and greater control on finishes.

This type of construction requires a restructuring of entire conventional construction process to enable interaction between design phase and production planning in order to improve and speed up construction.

Fig: 1.1 precast slab panels
Fig: 1.2 precast beam and girders
Fig: 1.3 Precast columns (1)
A load-bearing wall (or bearing wall) is a wall that bears a load resting upon it by conducting its weight to a foundation structure. The materials most often used to construct load-bearing walls in large buildings are concrete, block, or brick. Depending on the type of building and the number of stories, load-bearing walls are gauged to the appropriate thickness to carry the weight above them. Without doing so, it is possible that an outer wall could become unstable if the load exceeds the strength of the material used, potentially leading to the collapse of the structure.

II LITERATURE SURVEY

Mazen (2013) has stressed small openings yield minor effect on the load capacity of shear walls, cracking pattern and maximum drift. In case of small Openings, the shear walls behave as coupled shear walls. Thakkar (2012) has concluded that the design of shear wall is a complex procedure, especially if the cross section of the shear wall is not regular in shape. The design of shear walls takes horizontal forces into account by shear and bending. The design of shear in the walls can be managed by computing the shear stress distribution over the cross section and reinforcing appropriately. Potty (2008) has stated that the variation of deflection of one shear wall model to another is small. The difference in the deflection of shear wall modeled by beam element and the shell element is only 1.6mm for the ten storey building.

Habibullah (2007) has worked on physical object based analysis and design modeling of shear wall system using ETABS. It has been concluded that grouping of the area objects into piers is a very powerful mechanism to automatically obtain design moments and shear across a wall section from a finite element analysis. Ongjijundar (2007) had stressed that the large openings are generally achieved by use of large transfer beams to collect loading from the upper shear walls and then distribute them to the widely spaced columns that support the transfer girders.

Hasanet, al. (2011) has stressed that a new strengthening alternative for RC structures, namely exterior shear walls, has been experimentally investigated under reversed cyclic loading. Wdowickiet, al. (1993) has stressed calculating stress and displacements in three-dimensional shear wall structure with uniform properties throughout the height. The analysis is carried out on the basis of the continuous connection method. The system allows for considering lateral and gravity loads, arbitrary located in the plan and arbitrary distributed along the height. The system is user oriented and inexpensive in operation.

Jack et, al. (1968) carried out both rigidity and the strength of shear walls are highly variable so that even when loads known, the distribution of loads to the resisting walls are well as their response can only be studied using the methods of probabilistic structural mechanics. Bozdoganet, al. (2010) carried out vibration analysis of asymmetric shear wall structures using the transfer matrix method. He concluded that the governing differential equations of equivalent bending-warping torsion beam are formulated using the continuum approach. Xiaolei et, all (2008) worked on numerical analysis of cyclic loading test of shear walls based on open SEES.

Carpinteriet, al. (2012) carried out lateral load effects on tall shear wall structures of different height. The accuracy of the results is investigated by a comparison with finite elements solutions, in which the bracings are modeled as three-dimensional structures by means of shell elements. Biswas et,al. (1977) carried out three dimensional analysis of shear wall multi storey building. He studies the importance of torsion in multi storey building having a symmetric layout of shear walls.

Greeshmaet, al. (2011) carried out the analysis of flanged shear walls using ANSYS concrete model. It has been studied the possibilities of modeling reinforcement detailing of reinforcement models in practical use. Fabjanet, al. (2010) studied nonlinear analysis method for reinforced concrete buildings with shear walls. The different approaches for linear and non linear modeling of shear walls in structural analyses of buildings are studied and applied to RCC buildings with shear walls.

III. ANALYSES AND DESIGN

Shear wall structure having G+11 storey is analysed for garvity and laterial loads. The effect of axial force, out of plane moments, lateral loads, shear force, storey drift, storey shear and tensile force are observed for different stories. The analysis is carried out using ETABS and data base is prepared for different storey levels as follows
In this present study ground +11 storey shear wall building is considered for one acre of site with 350 units. Around 400sqft of carpet area per unit is taken with 300 units per floor. The constriction Technology is total precast solution with load bearing RCC shear walls and slabs. The modeling is done in ETABS as follows.

1. The structure is divided into distinct shell element. The shell element combines membrane and plate bending behavior, as shown in fig 3.1. It has six degrees of freedoms in each corner point. It is a simple quadrilateral shell element which has size of 24 x 24 stiffness matrix.

![Fig: 3.1 Shell elements](image)

2. Grid lines are made for the x, y and z coordinates and the wall is drawn from scratch.

3. Boundary conditions are assigned to the nodes wherever it is required. Boundary conditions are assigned at the bottom of the wall i.e., at ground level where restraints should be against all movements to imitate the behavior of shear wall.

4. The material properties are defined such as mass, weight, modulus of elasticity, Poisson’s ratio, strength characteristics etc. The material properties used in the models are shown in Table 3.1

<table>
<thead>
<tr>
<th>Material name</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of material</td>
<td>Isotropic</td>
</tr>
<tr>
<td>Mass Per Unit Volume</td>
<td>2.5kN/m²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>32kN/mm²</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.2</td>
</tr>
<tr>
<td>Concrete strength</td>
<td>30MPa</td>
</tr>
<tr>
<td>Section name</td>
<td>Wall</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>150mm</td>
</tr>
</tbody>
</table>

5. The geometric properties of the elements are dimensions for the wall section.

6. Elements are assigned to element type, see Table 3.1

7. Loads are assigned to the joints as they will be applied in the real structure.

8. The model should be ready to be analyzed forces, stresses and displacements.

In ETABS single walls are modeled as a pier/spandrel system, that is, the wall is divided into vertical piers and horizontal spandrels. This is a powerful mechanism to obtain design moments, shear forces and normal forces across a wall section. Appropriate meshing and labeling is the key to proper modeling and design. Loads are only transferred to the wall at the corner points of the area objects that make up the wall. Generally the membrane or shell type element should be used to model walls. Here the shell type is used. There are three types of deformation that a single shell element can experience, are axial deformation, shear deformation and bending deformation see Fig 3.3.

![Fig 3.3 Deformation of a shell element](image)

Wall pier forces are output at the top and bottom of wall pier elements and wall spandrel forces are...
output at the left and right ends of wall spandrel element, see Fig: 3.4

Fig.3.4 pier and spandrel forces in ETABS

ANALYSIS RESULTS AND DISCUSSION

1. Effect of axial force on shear wall:
The load bearing wall structure mostly carries axial compression force and transfer on to the foundation. The entire vertical load of all the stories is carried by ground floor load bearing wall. In order to design that wall it is quite essential to understand the variation of axial force in the walls. This force in the shear wall is from worst load combination of gravity and lateral loads. For the worst load combination, the axial force in the wall is plotted on y-axis against at each storey level. From Fig. 3.7, it is observed that maximum axial force in storey one is 1026.764 kN. The difference in maximum axial force between storey 11 and 12 is 7.26%. It indicates that the variation in maximum axial force with storey level is linear for worst load combination.

Fig.3.7 Axial force on shear wall

3. Effect of storey lateral load on shear wall:
Most lateral loads are live loads whose main component is horizontal force acting on the structure. The intensity of these loads depends upon the building's geographic location, height and shape. For the worst load combination lateral load in the wall is plotted against each storey level. From Fig. 3.9, it is observed that maximum lateral load in storey 12 is 736.67kN. The difference in maximum lateral loads between storey 11 and 12 is 0.54%. It is observed from Fig. 3.9 that this is non-linear variation of lateral load.

Fig.3.9 Lateral loads on shear walls

2. Effect of out-of-plane moments on shear walls:
Load bearing RCC walls are slender compression elements subjected to in and out-of-plane bending. For the worst load combination, out-of-plane moments in the wall is plotted on y-axis against at each storey level. it is concluded from Fig 3.8 that the maximum out-of-plane moments in walls of storey one is 142.603kN-m. The difference in maximum out-of-plane moment between storey 11 and 12 is 9.04%. It indicates that the variation in maximum out-of-plane moment with storey level is linear for worst load combination.

Fig.3.8 Out of plane moments on shear walls

4. Effect of shear force on shear wall:
Shearing forces are unaligned forces pushing one part of a body in one direction, and another part the body
in the opposite direction. For the worst load combination shear force in the wall is plotted against at each storey level. From the Fig.3.10, it is observed that maximum lateral load in storey one is 5526.73 kN. The difference in maximum lateral loads between storey 11 and 12 is 19.98%. It indicates that the variation in maximum shear force with storey level is non-linear for worst load combination.

5. Effect of storey drift on shear wall:
One of the major shortcomings high-rise structures is its increasing lateral displacements arising from lateral forces. For the worst load combination storey drift in the wall is plotted on y-axis against at each storey level. From the Fig.3.11, it is observed that maximum storey drift in between storey 12 is 0.199 mm. It indicates that the variation in maximum storey drift with storey level is non linear for worst load combination.

Design of walls
The present structure is considered as precast load bearing wall structure. In that the main or load bearing wall are of 150mm thickness. The typical wall layout for two units is shown in fig: 3.14. The design procedure of the load bearing wall is described as follows.

The connection details in the precast construction plays vital role. This is an investigation of the seismic response on the precast structures due to the wall to wall and wall connection behavior. Earthquake could damage the whole structure if it is not properly designed, especially in high seismic regions. Connection is one of the crucial elements to limit building damage. A lot of researches have been done on monolithic reinforced concrete buildings but none of them gives information on the behavior of precast connection under seismic effect for the whole structure. Although several moment resistant connections are designed through researches to sustain high intensity seismic, the connection fabrication is complex which will slow down the construction period. Besides, the actual behavior of these connections is still vague. The understanding of the actual connection behavior is very important, especially designed and constructed for high seismic region.

A precast technology offer benefits such as reduce construction period, better quality control, cleaner and safer construction sites and others. Precast concrete means concrete which has been prepared for casting and the concrete either is statically reinforced or prestressed. Meanwhile a precast concrete element is of a finite size and must therefore connect with
other elements to form a complete structure. When two elements are connected, problems such as shrinkage, thermal or load will induced strains and cause volumetric changes. The volumetric changes cause movement between the two elements and internal friction between the two elements surface is provided by using various methods such as inserting dowel between wall to wall connections. Apart from that, local crushing at the top of wall occurs due to the flexural rotation. Therefore, a bearing pad is provided to overcome this problem. Another factor need to be considered is the narrow bearing of the suspended element on the vertical element. Consideration for the overall stability of the structure is important too. Precast concrete structure refers to the combination of precast concrete elements and the structure is able to sustain vertical and horizontal loads or even dynamic loads. So the design and construction of the joints and connections is important to ensure the stability and robustness of the overall structure

Basic mechanism of structural connections

The mechanical behavior of structural connection can be characterized by the relationship between transferred force and corresponding displacement, for instance relations between tensile force and elongation, bending moment and rotation, shear force and shear displacement. A principal load-displacement relationship is shown in Fig.1. In ordinary design, the maximum resistance $S_{\text{max}}$ and stiffness $k = s/u$ in the service state are primary interest. Very often the load-displacement relationship is non-linear and a characteristic stiffness to be used for service state verification can be defined by the secant modulus of a certain appropriate load level.

<table>
<thead>
<tr>
<th>STOREY</th>
<th>Lateral force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>25.94</td>
</tr>
<tr>
<td>02</td>
<td>55.88</td>
</tr>
<tr>
<td>03</td>
<td>97.78</td>
</tr>
<tr>
<td>04</td>
<td>151.66</td>
</tr>
<tr>
<td>05</td>
<td>217.52</td>
</tr>
<tr>
<td>06</td>
<td>293.35</td>
</tr>
<tr>
<td>07</td>
<td>387.14</td>
</tr>
<tr>
<td>08</td>
<td>494.90</td>
</tr>
<tr>
<td>09</td>
<td>604.65</td>
</tr>
<tr>
<td>10</td>
<td>730.37</td>
</tr>
<tr>
<td>11</td>
<td>734.36</td>
</tr>
<tr>
<td>12</td>
<td>736.67</td>
</tr>
</tbody>
</table>

WALL TO WALL CONNECTIONS

AS PER IS: 11447-1985 CODE OF PRACTICE FOR CONSTRUCTION WITH LARGE PANEL PREFABRICATION

Vertical joints: Shear resistance of vertical joints shall be checked by the following formulae:
Keyed joint: Shear strength of reinforced keyed joint
\[ R_j = 0.12 \frac{\sigma_{kc}}{\gamma_w} (A_k + A_{ct}) + 2000 \Delta A_s \]

\( R_j \) = Ultimate shear capacity of the joint
\( \sigma_{kc} \) = Characteristic strength of concrete
\( \gamma_w \) = Strength reduction factor
\( A_k \) = area of the key under consideration
\( A_{ct} \) = total area of cross-section of shear-keys in the joint and area of cross-section of tie-beam respectively.

PVL140 is chosen from the peikko group technical manual for PVL Connecting loop. The minimum dimensions are as follows:

\[ \sigma_{kc} = \text{Characteristic strength of concrete} = 30,000 \text{N/mm}^2 \]
\[ \gamma_w = \text{Strength reduction factor} \]

Depends on eccentricity for external wall \( e = 0.2t_w \) subjected to a maximum of 30 mm = 0.2

\[ \text{and} \quad t_w = \frac{3.0}{0.15} = 20 \]

\( \gamma_w \) from the table 1 IS:11447-1985 is = 0.31

\( A_k \) = area of the key under consideration = 0.01795 m²

\( A_{ct} \) = total area of cross-section of shear-keys in the joint and area of cross-section of tie-beam respectively. = 0 (no tie beams are consider)

\( A_v \) = area of the transverse reinforcement in the key

From piekko manual 9mm diameter wire is chosen

\[ R_j = 0.02 \frac{\sigma_{kc}}{\gamma_w} (A_j + A_{ct}) \]

Where
\( R_j \) = Ultimate shear capacity of the joint
\( \sigma_{kc} \) = Characteristic strength of concrete
\( \gamma_w \) = Strength reduction factor
\( A_j \) = area of cross-section through the joint, while calculating \( A \), the portion of width less than 30 mm shall be neglected.

As per piekko group manual Picture 2, 4 no’s of loops are provided for each wall.

Therefore,

\[ R_j = 0.12 \frac{30000}{0.31} (0.01795 + 0) + 2000 \times 6.3585 \times 10^{-5} \]

= 209.8 kN (for one loop)

740 kN is the maximum lateral force on shear walls.

Grooved joint:

\[ R_j = \frac{\sigma_{kc}}{\gamma_w} (A_j + A_{ct}) \]

As per piekko group manual Picture 2, 4 no’s of loops are provided for each wall.

Therefore, 740 kN is the maximum lateral force on shear walls.

VI. CONCLUSION

In the present work ETABS is used to analysis the shear wall structure of G+11 considering the gravity and lateral loads. The following conclusion is drawn from present work. The variation of axial force with stories is linear. The difference in maximum axial force between storey 11 and 12 is 7.26 %. The variation of out-of-plane moment with stories is linear. The difference in maximum out-of-plane moment storey 11 and 12 is 9.04 %. The variation of lateral loads with stories is non-linear. The difference in maximum lateral loads between storey 11 and 12 is...
0.54% The variation of shear force with stories is non-linear. The difference in maximum shear force between storey 11 and 12 is 19.98%. Variation of storey drift with storey is non-linear. The maximum storey drift in storey 12 is 0.199 mm. Variation of storey shear with storey is non-linear. The maximum storey shear in storey one is 608.25 kN. The variation of tensile force with stories is non-linear and the difference in maximum tensile force between storey 11 and 12 is 20.02%. The variation of out-of-plane moments with storey level is non-linear. The difference in maximum out of plane moment between Zone-II and Zone-V is 29.25% and the difference in maximum out of plane moment between wind speeds 39 and 50 m/s the difference in shear force is 67.4%. The variation of shear force with storey level is non-linear. The difference shear force between zone-II and zone-V is 27.77% and for wind speed of 39 m/s and 50 m/s the difference in shear force is 36.126%. The variation of tensile force with storey level is non-linear. The difference in maximum tensile force between storey 11 and 12 is 51.92% for zone –II and that of for zone-V is 51.47%. The difference in maximum tensile force for wind speed of 39 m/s and 50 m/s is 13.17% and 19.84% respectively. The maximum storey drift is increasing while increasing the storey level. It is observed that maximum storey drift in between storey 11 and 12 is 0.21 mm for zone-II and for zone-V is 0.735 mm. The maximum storey drift for wind speed of 39 m/s and 50 m/s is 0.0340 mm and 0.591 mm respectively. The difference in maximum lateral loads between storey 11 and 12 is 0.54% for zone-II and 3.84%, for zone-V. Maximum lateral load for wind speed 39 m/s and 50 m/s 146.00 kN and 240.30 kN respectively. The variation of lateral force with storey level is non-linear. The variation in maximum storey shear with storey level is non-linear for worst load combination. The maximum storey shear in storey one is 907.77 kN for zone- II and for zone –V is 1958.46 kN, and for wind speed 39 m/s and 50 m/s the maximum storey shear is 2403.15 kN and 3762.32 kN respectively.

REFERENCE

[8] Alberto carpinteri, Mauro corrado, Giuseppe lacidogna and Sandrocammarano “lateral load effect on tall shear wall structure of different height” structural engineering and mechanics, vol. 41, No.3 PP 313-337.


