*ENGINEE*R - Vol. XXXXIII, No. 03, pp. [page range], 2010

Computer Aided Design of Modern High-Rise Building

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Abstract: The major cities of Sri Lanka are fast changing with many residential apartment buildings constructed. One of the primary requirements is the provision of car parking for which the lower floors are generally used. The car parks have a certain grid requirement for vertical load carrying members primarily arising due to guidelines specified in Building Regulations. Often, this grid arrangement is not suitable for the residential apartment above. Therefore, it is necessary to introduce a load transfer method at the starting of the apartment floors. This paper describes a complete design of a load transfer plate using finite elements as a solution to a 25 storied reinforced concrete building in Colombo, Sri Lanka which has car parking floors up to 5th storey. Further it is recommended to apply transfer plate concept as a solution to various space requirements and advancements of architectural features in modern high-rise building.

Keywords: Car parking, Grid, Building regulation, Load transfer plate, High-rise building

1. Introduction

When considering the present situation in major cities of the country, land is a scare resource. So every bit of land is precious and it is used for some important purpose. Thus, high rise apartment buildings are in demand. The current trend is to use the entire land for the structure and provide several parking floors within the building rather than providing parking outside [5]. The suitable column grid of an apartment floor will never match that of a parking floor which gives rise to the issue of connecting the two sets of columns together. There are several ways of connecting the two floors. Either girders or plates can be used as the transfer system. The selection of the system depends on the architectural features of the apartments and the client requirements. The project which I undertook was a 25 storeys reinforced concrete building, located in No.61, Green Path, Colombo 06, Sri Lanka. The proposed building will be used as a residential building with car parking up to 5th storey level and floor area at each floor level is 788 m^2. In this project, at the structural design stage, client requested to change the transfer beams and column grids at 6th storey since it was affecting the internal view of the residential apartment but the client also requested to keep the external views as per the architectural drawings. Therefore structural engineers had to face a challenge to find a suitable structural system for the building.

2. Objectives

The objective of this project is to introduce a thick plate for transferring loads from residential floors to columns continue from the car parking floors as a solution to safeguard the internal and external architectural requirement of residential apartments. Determination of a proper way to model a thick transfer plate in finite elements is also looked at in addition to obtaining the design parameters of the transfer plate from the finite element model.

3. Methodology

First a typical apartment layout and a parking layout were selected that satisfied the building and parking regulations. Foundation system was selected as bored piles with pile caps to satisfy existing soil condition at site.
The final structural system was selected as columns, beams and slabs up to 5th floor, load transfer plate at 6th floor level and wall and flat slabs from 6th floor to roof. The analysis was done based on a finite element model in SAP2000 with seven load combinations. Lateral stability was measured in terms of fundamental period of vibration and deflection for wind loads. The wind load analysis was carried out according to CP3: chapter V as it is widely used in Sri Lanka.

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4. Car parking regulations

It is necessary to allow space for vehicle turning circles, parking stalls, ramps, driveways etc... when arranging a parking floor. This must be done satisfying the parking regulations in Sri Lanka. As a result, the vertical load carrying members should have a certain grid requirement [6]. Columns are the most suitable elements to transfer vertical loads and the dimensions of a suitable column grid are largely dependent on the parking regulations. This study is limited to relevant regulations for standard vehicle type, such as car equivalent, two and three wheelers. More evidently, multi-storey car parks in high rise apartment buildings are designed for car equivalent, two and three wheelers.

Table 1: Minimum plan dimensions of Parking Stalls

Vehicle Type	Stall width (m)	Stall length (m)
Standard (Car equivalent, also to be used for two and three wheelers	2.4	4.8

Table 2: Minimum width of Aisles

Parking Angle (Degree's)	One way traffic one sided bays (m)	One way traffic two sided bays (m)	Two-way traffic (m)
00^0 Parallel	3.6	3.6	6.0
30^0 Angle	3.6	4.2	6.0
45^0 Angle	4.2	4.8	6.2
60^0 Angle	4.8	4.8	6.4
90^0 Angle	6.0	6.0	6.0

Table 3: Minimum inner and outer Turning Radius

	Passenger Car
Inner turning radius (m)	7.3
Outer turning radius (m)	4.7

5. The need of different grids for the proposed apartment building and solution with transfer plate

The proposed residential apartment building at green path, Colombo 7, Sri Lanka has 6 car parking floors with one at basement level. The other floors from 6^{th} storey level to 25^{th} storey level are residential apartment floors. Each of these residential floors has six apartments with advanced architectural features. Therefore to cater the different space allocation needs of the apartment floors and the parking floors, primarily arising due to building regulations and traffic regulations, it was necessary to have different grids in the same building. As a result of this situation, regular column grid has been changed at the sixth storey level with a transfer plate and concrete walls.

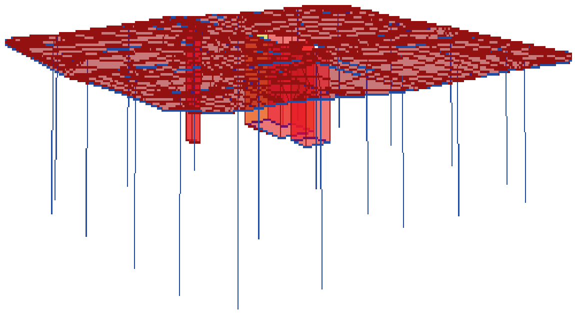

Figure 01: Column layout below the transfer plate

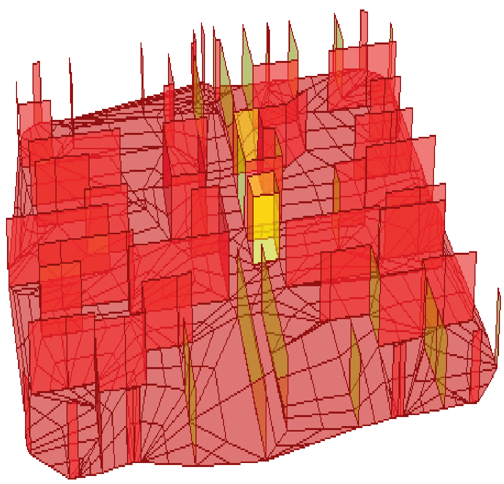

Figure 02: Wall layout above transfer plate

6. Transfer plate – SAP2000 model

It is necessary to select a correct finite element to represent the behavior of the transfer plate; in this case a shell element was selected to represent the transfer plate. However, there are certain issues when using shell elements. The height of the stories above and below the transfer level must be increased to maintain the overall height of the structure. This is because of transfer plate element thickness does not add to the height of the building at the common connecting point of top and bottom column elements and transfer plate elements [8]. Another concern of using shell elements for this situation is that of Shearing deformations. Shearing deformations tend to be important when the thickness of the element is greater than about one –tenth to one-fifth of the span. They can also be quite significant in the vicinity of bending-stress concentrations, such as near sudden changes in thickness or support condition, and near holes or re-entrant corners. Thus, shearing deformations had been taken into account by selecting shell element properties as thick plate. This formulation includes the effects of transverse shearing deformation [5]. However, there are important aspects that a design engineer must be aware of in this situation. All shell elements must be properly connected to adjoining elements to have proper connectivity and these elements should be connected with different column grids while maintaining connectivity and keeping orientation.

7.0 Meshing for better results

In any finite element model the finer the mesh more accurate are the results. This is particularly important in this situation as concentrations of stress are most likely around columns that are transferred. Further more, as explained earlier the use of the thick-plate formulation implies that the shell elements are more sensitive to large aspect ratios. If a coarse mesh is to be used, elements with large aspect ratios are most likely particularly in the vicinity of the loads (columns that are transferred).

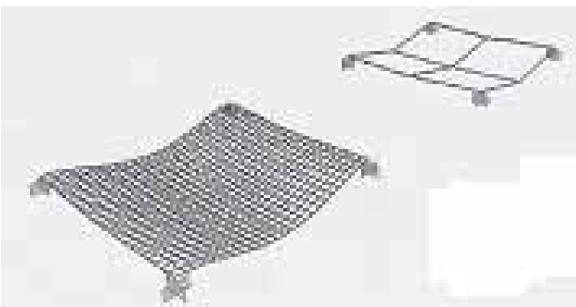

Figure 03: The behavior of a fine mesh and a coarse mesh

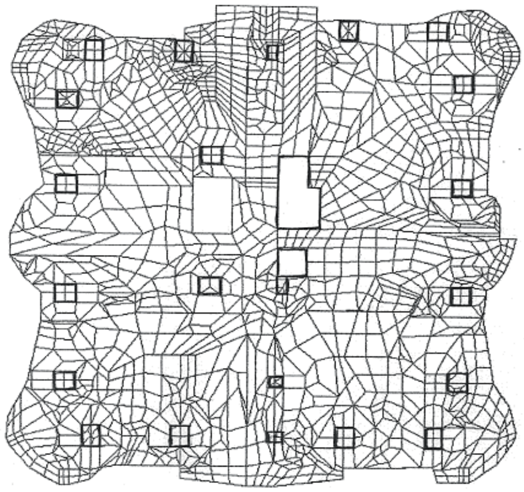

Figure 04: Transfer plate model

8. Complete Model – SAP2000

The complete modeling was carried out after selecting proper finite elements to represent all the structural members, finalizing initial member sizes and support conditions. Support conditions were selected as pin to transfer loads from column to pile foundation. In addition to the selection of element type for transfer plate as thick plate shell element, the other element types were selected to represent column, beam, slab and wall. Column and beam were represented by frame elements while slab and wall were represented by shell elements. Modeling was carried out step by step. First pin supports were introduced at column positions with ground beams and slabs at basement location and then as to the conventional beam, slab and column system; all the columns, beams, lift walls, slabs, ramps and stair cases were modeled up to the 6th storey level. At the second stage of modeling transfer plate was modeled by connecting column grids and wall grids rising upward from transfer plate. After introducing suitable wall grids for apartment walls at 6th storey, the typical 7th storey was modeled with a flat slab and repeated up to roof level with stair cases and lift walls. A few walls and lift walls were extended from the roof level to support for lift machine room and water tank. The building model was completed after modeling the lift machine room and the water tank.

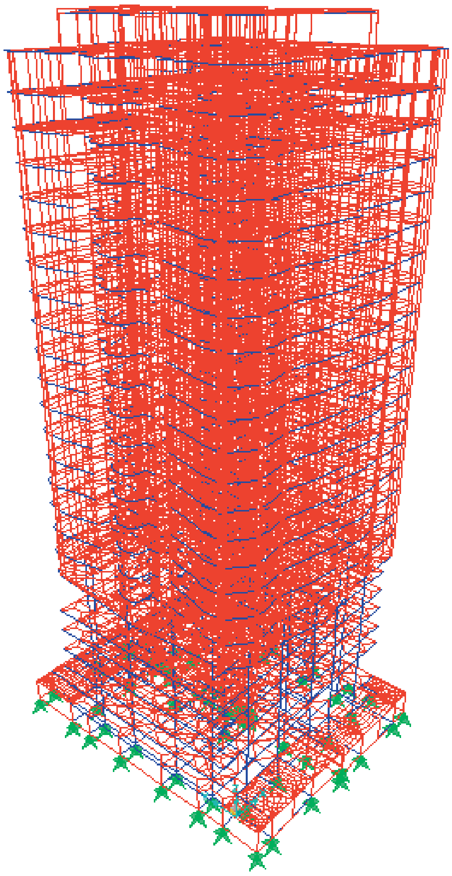

Figure 05: Complete 3 D Model

9. Loading :

Dead and Imposed loadings on building were calculated by using BS 6399 Part I: 1984, British standard of design loadings for buildings and Wind loadings were calculated from CP3: Chapter V: Part 2: 1972, code of basic data for the design of buildings. Considering the construction difficulties with using deferent concrete grades for structural elements; grade 40 concrete (f_{cu} = 40 N/mm^2) was selected for all structural members. Further, in the analysis part seven different load combinations were introduced and analyses were carried out for all structural members to have greater safety.

10. Analysis:

Analyses were carried out for the following seven different load cases; in addition to considering wind load from two directions.

Load Case 1 - All span with maximum load (1.4 DL + 1.6 IL)
Load Case 2 – Span loaded with maximum / minimum / maximum load combination
Load Case 3 - Span loaded with minimum / maximum / minimum load combination
Load Case 4 – 1.4 DL + 1.4 WL
Load Case 5 – 1.2 DL + 1.2 IL + 1.2 WL
Load Case 6 – 1.4 DL – 1.4 WL
Load Case 7 - 1.2 DL + 1.2 IL - 1.2 WL

Fine meshes were used for typical apartment floors and transfer plate to study the effect of meshing at load transfer locations. The mesh generation and the stress contours for S_{11} (Stresses in direction 11 for Load case 1) at transfer plate are shown below for two models.

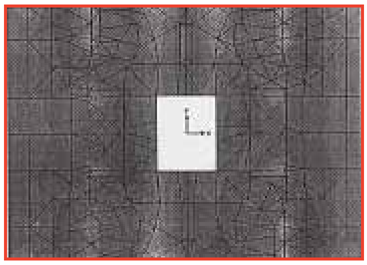

Figure 06: Mesh generation and the stress contours for Model-1

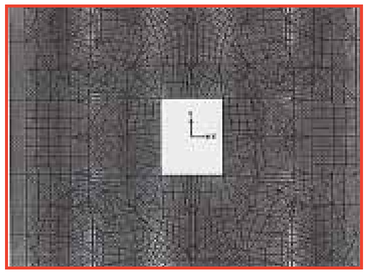

Figure 07: Mesh generation and the stress contours for Model-2

11. Results:

11.1 Lateral Stability Analysis

Table 4: Deflection and fundamental period of vibration

Parameter	Value
Fundamental period of vibration	2.00 sec.
Maximum deflection for wind loads	24 mm
Maximum vertical deflection of transfer plate	10 mm
Maximum lateral deflection of transfer plate	3.5 mm

From these results it is seen that there is an important aspect of low value vibration period. Based on rule of thumb, the acceptable value is about 2.5 sec for a 25 storey building, but in this case it is 2.00 sec. It seems that the apartment above the transfer plate contributes much more than the structure below the transfer plate due to high stiffness of the building up to the transfer plate level. It also can be seen that lateral deflections of the transfer plate level is only 3.5mm but at the tip of the building is 24mm. Therefore, it is clear that lateral deflections of the transfer plate and below are at a minimum. Effectively, the apartment structure behaves as it is supported on a rigid foundation.

Designing the transfer plate

Table 5: Critical stress in the transfer plate

Maximum stress N/mm^2	Top surface	Bottom surface
Compression (S_{11})	13.74	26.32
Tensile (S_{11})	24.32	10.82
Compression (S_{22})	8.37	17.20
Tensile (S_{22})	18.27	9.45

* S_{11} – Stress in direction 11
S_{22} – Stress in direction 22
M_{11} – Moment in direction 11
M_{22} – Moment in direction 22

It can be seen from the analysis results that the highest stresses are located at around the column and do not progress for lengths more than 1-1.5m (Figure: 07). The design steel can be calculated either based on stress S_{11} and S_{22} or directly using M_{11} and M_{22}.

12. Conclusion

It can be concluded that the transfer plates can be used effectively as outriggers in apartment buildings. It will allow changing column grids above to project architectural features within apartments. A proper finite element model gives the required design parameters for the transfer plate itself and parameters regarding the lateral behavior of the structures. Once a thick plate is used, the effects of the floors below the transfer level have no considerable impact on the lateral behavior of the overall building. It will act as a rigid component without much deflection.

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