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CONVERSION OF MDOF SYSTEM INTO SDOF SYSTEM OF RC WAFFLE SLAB STRUCTURE BY USING N2 METHOD

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Abstract - whenever large spaces within a building need to be enclosed without obstructions and supports, architects often deploy waffle slabs to construct floors and ceilings. As a result of the development in architectural design and new building management concepts, waffle slabs are becoming on demand for structural designers. Therefore, it becomes important to know more about its structural behavior. In the present work, the pushover analysis of a single storey waffle slab structure is performed both in x and y directions. The parametric study is also conducted on the basis of different column conditions. The software used in the analysis is ETABS. Based on the parametric study, a problem of waffle slab structure is taken and converted the MDOF system into SDOF system by using N2 method. The results obtained from the analysis such as capacity curves, deflection, stresses, displacement and base shear are compared.

Key Words: **Waffle Slab, Pushover analysis, N2 Method, SDOF, MDOF**

1. INTRODUCTION

1.1 Waffle Slab

Whenever large spaces within a building need to be enclosed without obstructions and supports, architect often deploy waffle slabs to construct floors and ceilings. As a result of the evolution in architectural design and new building management concepts, waffle slabs are becoming on demand for structural designers. Therefore, it becomes important to know more about its structural behavior.

The slab with an arrangement of intersecting beams placed at regular interval and interconnected to a slab of nominal thickness is known as Waffle slab. Waffle slab is also known as two-way ribbed slab. These slabs are used when a large column free area is the main requirement. They are used for heavy loads and large span structures as they exhibit higher stiffness and smaller deflection. Void formed in the ceiling leads to reduction in dead load and is beneficially utilized for concealed architectural lighting. Waffle slab can be used as both ceiling and floor slab. Waffle slabs are used for specialized projects that involve clean rooms, spaces requiring isolation from low frequency vibration or those needing low floor deflections. Waffle slabs are mainly used in airports, parking garages, industrial and commercial building, residences and other structures requiring extra stability.

Fig.1. Waffle slab structures

1.2 Pushover Analysis

The pushover analysis of a structure is a non-linear static analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out upto failure, thus it enables determination of collapse load and ductility capacity. On a building frame, plastic rotation is monitored and lateral inelastic force versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified.

1.3 N2 Method

N2 method was developed in the mid 1980's by Fajfar. N2 method is non-linear method for the seismic analysis of structures. N stands for Non-linear analysis and 2 stands for two mathematical models as single degree of freedom system and multi degree of freedom system. It combines the pushover analysis of a multi- degree-of-freedom (MDOF) model with the response spectrum analysis of equivalent single-degree-of-freedom (SDOF) system. The N2 method has been formulated in the acceleration – displacement format (Fajfar 1999), in which the lateral load pattern in pushover analysis is related to the assumed displacement shape. The method is formulated in the acceleration -

displacement format, which enables the visual interpretation of the procedure and of the relations between the basic quantities controlling the seismic response. Inelastic spectra, rather than elastic spectra with equivalent damping and period, are applied. This feature represents the major difference with respect to the capacity spectrum method. The development of the N2 method started in the mid-1980's (Fajfar and Fischinger 1987, Fajfar and Fischinger 1989) [5].The method has been gradually developed into a more mature version (Fajfar and Gašperšič 1996). Recently, following Bertero's (Bertero 1995) [3] and Reinhorn's idea (Reinhorn 1997) [12], the N2 method has been formulated in the acceleration – displacement format (Fajfar 1999) [6], in which the lateral load pattern in pushover analysis is related to the assumed displacement shape. This feature leads to a transparent transformation from a multi- degree-of-freedom (MDOF) to an equivalent single-degree-of-freedom (SDOF) system. In the proposed N2 Method, two different mathematical models and three steps of analysis are used. In the first step, stiffness, strength and supplied ductility are determined by non linear static analysis of MDOF system under a monotonically increasing lateral load. Then, in the second step, an equivalent single degree of freedom system is defined with assuming that the deflected shape does not change during an earthquake. The non linear characteristics of equivalent system are based on the base shear vs top displacement relationship, obtained by the non linear static analysis in the first step. In third step of N2, maximum displacement is determined by carrying out non linear dynamic analysis of the equivalent SDOF system (Fajfar and Fischinger, (1998)) [5].

2. Methodology and Modeling

Following methodology is adopted:

- An extensive survey of the literature on the response of waffle slab to seismic loading is has been performed.
- The parametric study of the waffle slab structure with four different columns conditions has been taken and analyzed by the Pushover Analysis.
- The results of analysis such as capacity curves, stresses, deflection, hinge mechanism, displacement and base shear are compared for different column conditions.
- Based on the parametric study, a problem of Waffle Slab structure has been taken and converted into SDOF model with the help of N2 method.

  The seismic analysis of waffle slab structure is determined in the current project with the help of Pushover analysis by using ETABS software.

Table1. Description of the structure

PARTICULARS	DETAILS
Structure	Waffle slab(15mx21m)
Number of storey	1
Storey Height	5m
Column section	0.5mx0.4m
Beam Section	0.350mx0.200m
Slab Thickness	0.230 m
Beam Spacing	1m
Live Load	2 KN/m ^{2}
Grade of Concrete and Steel	M25 and FE415

The parametric study is done on the basis of different column conditions and the structures are as follows-

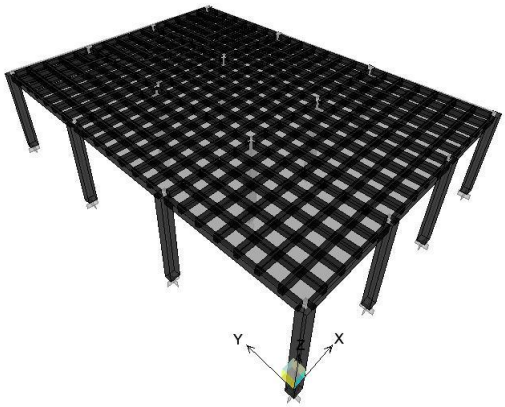

Fig.2. Waffle slab structure supported on columns along X and Y direction

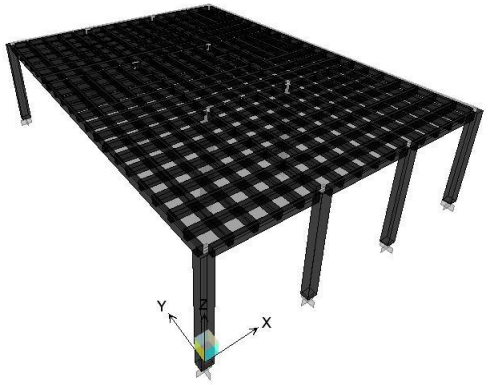

Fig.3. Waffle slab structure supported on columns along X direction

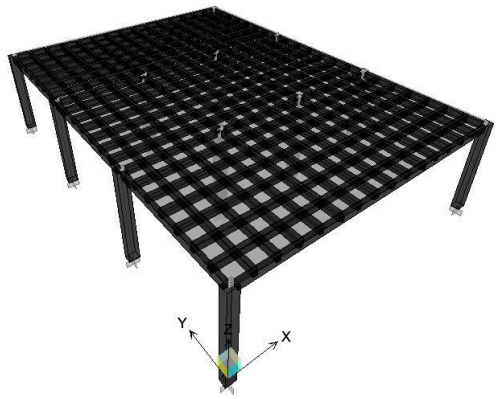

Fig.4. Waffle slab structure supported on columns along Y direction

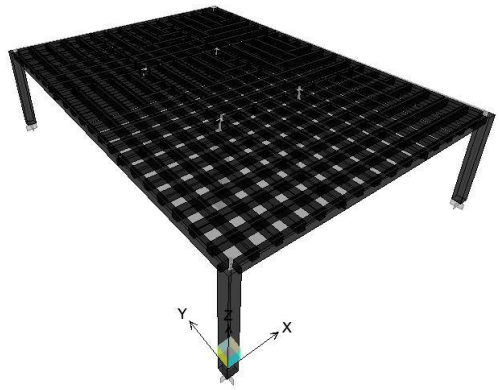

Fig.5. Waffle slab structure supported on columns at four corners

3. RESULT AND DISCUSSION

The pushover analysis is carried out for the mode type lode pattern in both x and y directions on waffle slab structure for different column conditions. Default hinge properties, available in programs based on the FEMA 356 and Applied Technology Council (ATC-40) guidelines are used for frame member. Plastic hinge is used to represent the failure mode in the beams and columns when the member yields.

3.1. Capacity curve

Capacity curve is defined as the plot of the total lateral force on a structure against the lateral displacement of the roof top of the structure. It is also called pushover curve. The comparative curve of different analysis cases are shown in fig. 6 and fig. 7.

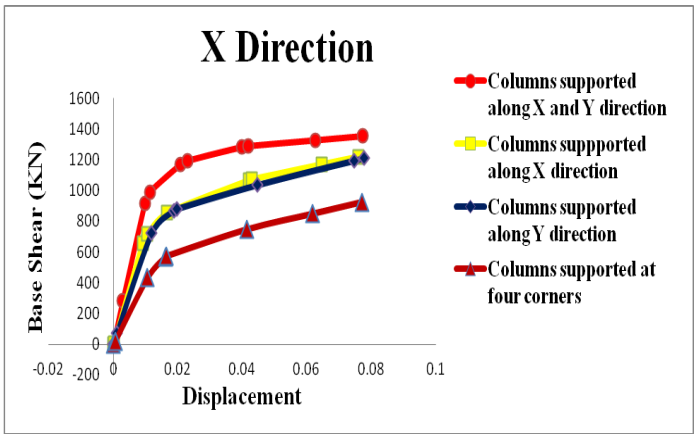

Fig.6. COMPARATIVE PUSHOVER CURVES FOR DIFFERENT CASES OF MODE TYPE LOAD IN X DIRECTION

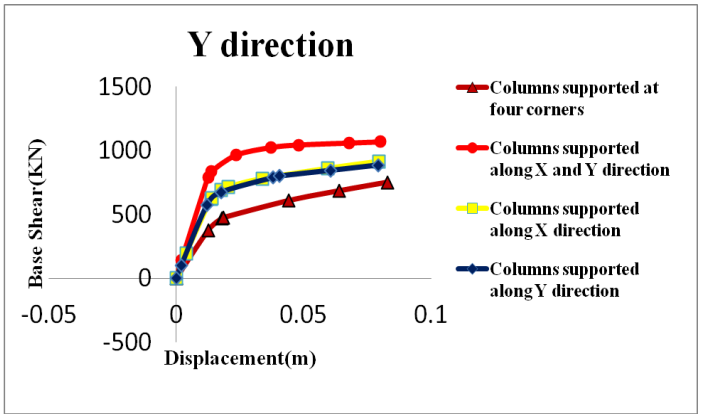

Fig.7. COMPARATIVE PUSHOVER CURVE FOR DIFFERENT CASES OF MODE TYPE LOAD IN Y DIRECTION

3.2. Statistics of plastic hinges

Hinges are formed both in beams and columns. In the structure with columns supported at four corners, the hinges reached upto collapse point and in all the other three cases, the hinges are limited to Collapse Prevention point.

3.3. Deflection in waffle slab structure

The permissible limits of deflection in the structure (as per IS 456:2000) is span/250, i.e. 60 mm in x direction and 84 mm in y direction .In the structure supported on columns along X direction, the deflections for modal type load pattern in x and y directions are 58 mm and 69.2 mm respectively. These values are within the permissible limits of deflection and for other cases, the values of deflection exceed the permissible limits.

3.5. Stresses in waffle slab structure

The permissible stresses in waffle slab structure (as per IS 456: 2000) for concrete is $0.446*f_{ck}$ i.e. 11.15 N/mm^2. Based on parametric study, the structure supported on columns along x direction is within the permissible limits.

3.5. Results of N2 Method

After conducting the parametric study of the structure, the waffle slab structure supported on columns along X direction is considered for conversion from MDOF system to SDOF system. This case is considered because the results of deflection and stresses are within the permissible limits

Equivalent results for SDOF model are

- Equivalent Force (F)* = 51.5903KN
- Equivalent Displacement (D*)= 4.40mm
- Equivalent Mass (M*)= 3279KN
- Equivalent Stiffness (K*)= 11.725KN/mm

4. CONCLUSIONS

1. Pushover analysis is carried out separately in the X and Y directions. The slope of the pushover curves is gradually changed with increase of the lateral displacement of the building. Hinges have developed in the beams and columns showing the three stages immediate occupancy, Life safety, Collapse prevention.

2. On the basis of pushover curves, the structure shows less displacement corresponding to their maximum base shear in X direction for all the cases as compared to displacement in Y direction.

3. The maximum permissible limit of deflection as per IS 456:2000 i.e. span/250. For the structure supported on columns along X direction, the deflections are within permissible limits.

4. The Maximum permissible stresses in concrete is 0.446*fck i.e. 11.15 N/mm^2. For the structure supported on columns along X direction, the stresses are within permissible limits.

5. From results and discussions it can be concluded that the only case which gives better results on the basis of maximum permissible limit of deflection and stresses is the waffle slab structure supported on columns along X direction, for modal load pattern in Y direction. Hence, N2 method is applied for the same case only for conversion of MDOF system into SDOF system.

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