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

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***Abstract*— The use of flat slab building provide many advantages over the conventional RC frame building in terms of architectural flexibility, use of space, easier formwork and shorter construction time period. In the present work flat slab with perimeter beam having different column condition such as columns in x and y-direction, columns in x-direction, columns in y-direction and columns at four corners are considered. For earthquake loading, the provision of IS:1893-2002 are considered, the design and reinforcement detailing is carried out as per IS 456-2000. The modeling and seismic analysis is done with the help of analysis software SAP-2000 (version 17.3). The results of non-linear static analysis i.e. pushover analysis such as capacity curve, stresses, deformation , hinge mechanism, performance point, base shear of flat slab structure in mode type load pattern in both x and y direction for different column condition are compared and after parametric study, one of the problem of flat slab with has been taken for transformation of MDOF system to SDOF system with the help of N2-method.**

***Keywords* - Flat slab, non linear static analysis method, pushover analysis method, N2- method, modal participation factor, SDOF, MDOF, SAP 2000.**

I. INTRODUCTION

1.1. Flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural, functional and economical aspects. Because of the absence of deep beams and shear walls, flat-slab structural system is significantly more flexible for lateral loads than traditional RC frame system and this make the system more vulnerable under seismic events. The results from the analysis for few types of construction systems which is presented in the paper Apostolska et al.(2008) [1] show that flat slab system with certain modifications like design of beam in the perimeter of the building and RC walls can achieve rational factor of behavior considering Eurocode,8 (2004) and can be consider as a system with acceptable seismic risk. Modifications with additional construction elements improve small load bearing capacity of the system and increase strength and stiffness, improving seismic behavior of flat-slab construction system. According to IS 456-2000 the term flat slab means a reinforced concrete slab with or without drops supported, generally without beams, by columns with or without flared column heads. For design of flat slabs IS 456-2000 permits use of any one of the Direct Design Method and Equivalent Frame Method. The present study is made by using Direct Design Method. The reinforcement is provided in two or more directions as per requirements.

1.2. Single-degree-of-freedom (SDOF) system is a system whose motion is defined just by a single independent co-ordinate. It is a simplest vibratory system can be described by a single mass connected to a spring, the mass is allowed to travel only along the spring elongation direction.

1.3. Multi-degree-of-freedom (MDOF) system is one in which 2 or 3 co-ordinate are required to define complete positions of a system at any instance of time.

1.4. Methods of analysis at present various measures against the earthquakes are applied to the space structure. Pushover analysis has been widely used on earthquake response prediction of building structures under severe earthquakes, using the pushover analysis, a characteristic non-linear force - displacement relationship of the MDOF system can be determined and with the help of N2 method, the transformation of MDOF system to equivalent SDOF system and vice - versa follows from simple mathematics.

1.5. The nonlinear static procedure colloquially known as "pushover analysis," has become a standard method for estimating seismic deformation demands in building structures as well as their local and global capacities. 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 up to failure, thus it enables determination of collapse load and ductility capacity The static pushover method is also described and recommended as a tool for design and evaluation purpose by the National Earthquake Hazard Reduction Program NEHRP, FEMA Publication No. 273 (1997)[8] and has been updated in FEMA Publication No. 356 (2000)[9] guidelines for the seismic rehabilitation of existing building and represents a main component of Spectrum capacity analysis method ATC-40(1996)[2].

1.6. N2 method is a relatively simple nonlinear method for the seismic analysis of structures. It combines the pushover analysis of a multi- degree-of-freedom (MDOF) model with the response spectrum analysis of an equivalent single-degree-of-freedom (SDOF) system. 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. Moreover, demand quantities can be obtained without iteration. Generally, the results of the N2 method are reasonably accurate, provided that the structure oscillates predominantly in the first mode. The development of the N2 method started in the mid-1980s (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 share - top displacement relationship, obtained by the non linear static analysis in the first step. In third step of N2, maximum displacement and the corresponding ductility demand are determined by carrying out non linear dynamic analysis of the equivalent SDOF system.(Fajfar and Fischinger,1998)[5]

II. METHODOLOGY AND MODELING

The seismic analysis of flat slab is determined in the current project with the help of pushover analysis using SAP2000 (Version 17.3.0). For this, an extensive survey of the literature on the response of flat slab to seismic loading has been performed and the problem of flat slab with four different columns conditions has been taken and analyzed by the non-linear static pushover analysis and the results of analysis such as capacity curve, stress, deformation, hinge mechanism, performance point, base shear has been compared for different column conditions. Based on the parametric study the problem of flat slab has been taken and has been converted into SDOF model with the help of N-2 Method.

A typical flat slab with different column condition is considered in the present study, the height of the storey is 6 m and The overall plan dimension is 21 m x 15 m. The thickness of the slab is 185 mm. The materials used are M 20 grade concrete and HYSD Fe 415 grade steel. The slab of the structure is defined as shell layered/non-linear type with quick start option. The rebar layer has been taken as two layered. cross-sections of columns and beams are 0.6 m x 0.6 m for columns and 0.3 m x 0.6 m for beam for Case A. and 0.8 m x 0.8 m for columns and 1.2 m x 0.6 m for beam for remaining column condition.

The following four cases of different column condition have been considered:
Case A – Fat slab supported on column in X and Y direction
Case B – Flat slab supported on column in X direction
Case C – Flat slab supported on column in Y direction
Case D – Flat slab supported on column at four corners

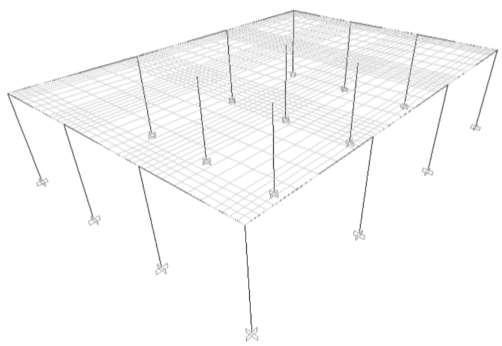

Fig. 1. Case A - flat slab supported on column in x and y direction. (wire mesh view)

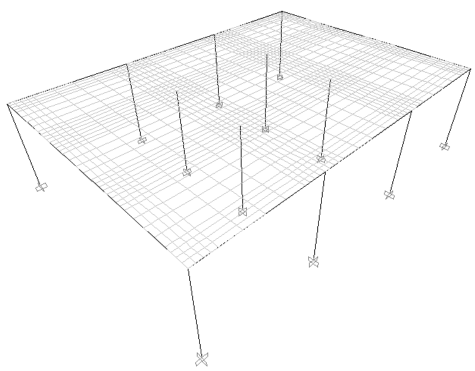

Fig. 2. Case B - flat slab supported on column in x direction. (wire mesh view)

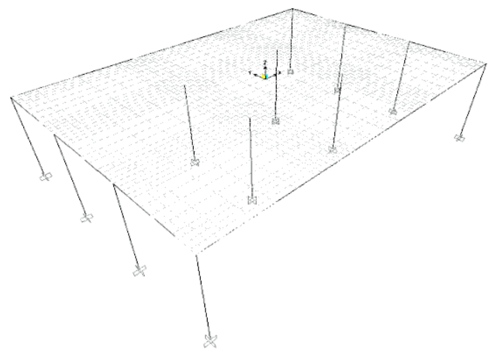

Fig. 3. Case C - flat slab supported on column in y direction.(wire mesh view)

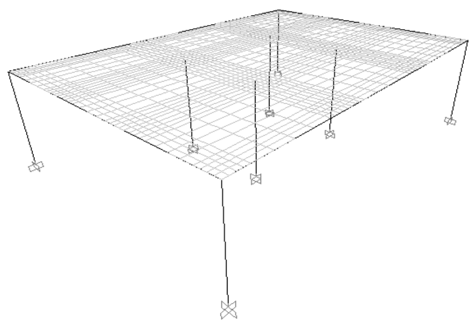

Fig. 4. Case D - flat slab Supported on column four corners.(wire mesh view)

III. RESULTS AND DISCUSSION

The pushover analysis is carried out as a mode type lode pattern in both x and y directions on flat slab for all the supporting 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 is define as the plot of the total lateral force on a structure against the lateral displacement of the roof top of the structure this is also called pushover curve. The comparative curve of different analysis cases are presented.

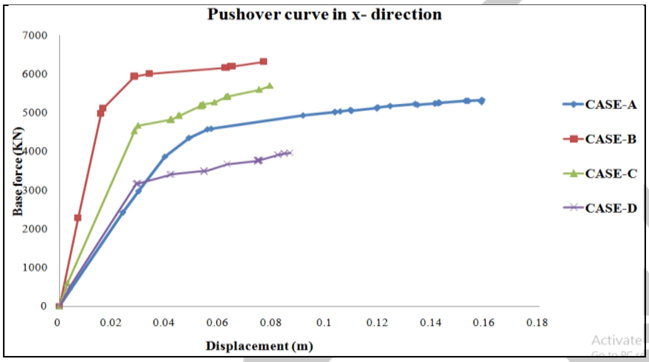

Fig. 5. Capacity curve in x-direction for different analysis curve

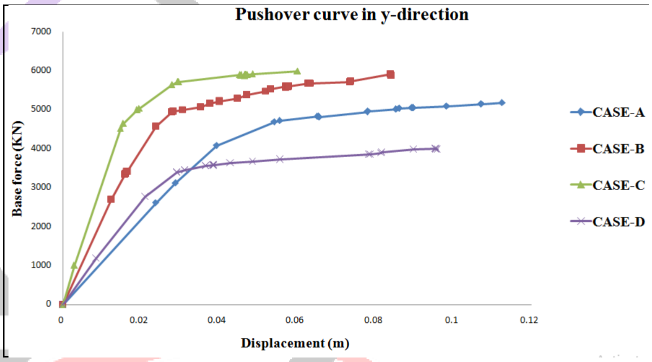

Fig. 6. Capacity curve in y-direction for different analysis curve.

3.2. Modal characteristics :- The modal participation mass factors are more than 75% in both x and y-directions, for all analysis case of columns conditions, which suggests that pushover analysis gives more realistic results**.**

3.3. Statistics of plastic hinges :-Hinges are formed in column and not in beams.
For, CASE-A (columns in x and y-direction) and CASE-D (columns at four corner), hinges are formed up to LS state in x-direction whereas in y-direction, hinges are formed up to IO.
For, CASE-B (columns in x-direction) and CASE-C (columns in y-direction), hinges are formed up to IO in both x and y-direction.

3.4. Deflection in flat slab :-The permissible deflection in (as per IS 456:2000) is span/250, i.e. 84 mm in x-direction and 60 mm in y-direction.
From the above results it is found that the permissible limits exceeds for all Cases except for Case-C (columns in y-direction), maximum deflection obtained in x and y-directions is 79 mm and 57 mm respectively, which is within the permissible limits.

3.5. Stresses in flat slab layers :- Stresses in 185 mm thick shell layered/ non -linear type flat slab with and top and bottom reinforcement for all analysis cases of different column condition.

The permissible stresses in flat slab (as per IS 456: 2000) are:-

- Permissible stress in concrete is $0.446*f_{ck}$ i.e. 11.15 N/mm²
- Permissible stress in steel is $0.87*f_y$ i.e. 361.05. N/mm²

For concrete : the permissible limits exceeds for all cases, except for CASE-C in y-direction.
For steel : the permissible limits exceeds for all cases, except for CASE-A in x-direction and in y-direction for CASE-B and CASE-C.

3.6. Results of N2 method :- Form results it is found that the only case which is qualify both the maximum permissible limit of deflection and stresses, is CASE-C (columns in y-directions) for mode type load pattern in y-direction, having deflection of 57 mm, and the stresses in concrete and steel is 10.06 N/mm² and 150.57 N/mm² respectively, hence N2 method is applied for the same case only, for conversion of MDOF system in SDOF system.

Equivalent results for SDOF model are :-

- Equivalent force = F* = 2474.03 KN
- Equivalent Displacement = D* = 15.15 mm
- Equivalent mass = M* = 1826.77 KN
- Equivalent Stiffness = K* = 205.76 KN/mm
- Elastic period = T* = 0.58 sec.

IV. CONCLUSION

1. Since flat slab has been modeled in layers, so it has become possible to observe the results in all the layers.
2. The pushover analysis is relatively a simpler way to explore the nonlinear behavior of structures and same is here applied for flat slab structures. Hinges are formed only in columns in every case.
3. The maximum permissible limit of deflection as per IS 456:2000 i.e. span/250 is 84 mm in x-direction and 60 mm in y-direction. The maximum permissible stresses in concrete is $0.446*f_{ck}$ i.e. 11.15 N/mm² and maximum permissible stresses in steel is $0.87*f_y$ i.e. 361.05 N/mm².
4. From results and discussion it can be concluded that the only case which qualifies both the maximum permissible limit of deflection and stresses, is Case-C : flat slab supported on columns in y-directions, 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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