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Research paper

Pushover Analysis of BTN Office Building in Madiun City Indonesia

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Abstract

Bank Tabungan Negara office building located in Madiun city, Indonesia. Construction of that building was finished in 2013. BTN office was designed according to SNI 1726 2002. In Indonesia there is revision code of SNI 1726 2002 by SNI 1726 2012. Since 2012 planning of building in Indonesia must be designed according to SNI 1726 2012. This research reanalyses this building to know performance level of the building. Pushover analysis use software analysis of structure ETABS version 9.00. Concrete strength used fc 25 MPa, bending reinforcement yield stress fy 400 MPa and shear reinforcement yield stress 240 MPa. Analysis result indicates that performance level of BTN office building is said Life Safety to Collapse Prevention (LS-CP). At the performance point get value of base shear is 1089 KN, and the maximum roof displacement is 127 mm.

***Keywords**: Pushover analysis; Reinforced concrete; Life safety; Collapse prevention*

1. Introduction

Bank Tabungan Negara (BTN) office building located at dr. Sutomo street, Madiun city, East Java, Indonesia. That building planned at 2012 and constructed in 2013. In the planning of BTN office building according to SNI 1726 2002. Indonesian National Standardization Agency (BSN) revised the regulations SNI related to building structure including SNI 1726: 2012 regarding Procedures for planning of earthquake resistance for buildings and non-building structures as a revision of SNI 1726-2002.

Rohman (2014) studied the comparison of the using SNI 1726 2002 and RSNI 1726 201X for analysing structural building in Madiun city. Results of the analysis shown that earthquake load according to SNI 1726 201X bigger around 27.5% and the distribution of load bigger on each floor. Using SNI 1726 2012 in the analysis of structure there is increasing earthquake loading [1].

The pushover analysis is a static non-linear analysis under gravity loads and gradually increasing lateral loads. Static pushover analysis can be used to evaluate the strength of the building structure, and it promises to be a useful and effective tool for performance-based design [2]. Pushover analysis may be applied to verify the structural performance of the existing buildings or new building structure.
In pushover analysis, the first step is to suppose a certain lateral load pattern, then performa static analysis of the structural model under this loading pattern. The load pattern is done step by step until a predetermined target displacement is reached. Target displacement is the maximum drift of the structure without total collapse under earthquake loads. Thus, the relationship between base shear and roof displacement is obtained, which is referred to as the capacity curve of building [3].
Software available to perform pushover analysis Extended Three Dimensional Buildings Systems (ETABS), Structural Analysis Program (SAP) 2000, ADINA, STAAD Pro etc. The software program can work with complex geometry and monitors deformationat all hinges. Default hinge properties use ATC-40 [4]□and FEMA 273[5]. That program can determine the ultimate deformation of the structure.

Structural analysis of this research use ETABS software version 9.00. Step analysis consist of modeling of structure, static analysis use gravity load and earthquake load, designing of concrete reinforcement and pushover analysis [6]. Pushover analysis shows the capacity curve and location of plastic hinges of the structures with the different number of story.
The purposes of this research is to know performance level of this building by pushover analysis use earthquake loading according to SNI 1726 2012.

2. Materials and methods

2.1. Object of Study

The object of this study is Bank Tabungan Negara (BTN) office building in Madiun city. The building is constructed from a reinforced concrete structural frame, and consist of 3 stories. The height of each column 4.0 m. Concrete strength use fc 25 MPa, yield stress of bending reinforcement fy 400 MPa and yield stress of shear reinforcement 240 MPa. Modulus elasticity of concrete E 23500 MPa. The dimension of beam and column can be shown in table 1 and geometry structure can be shown in figure 1. The thickness of the plate is 12 cm. Structure of this building is a symmetric structure. In the model, the support condition of the base was assumed to be fixed. The type of soil is medium soil or site class SD according to SNI 1726 2012.

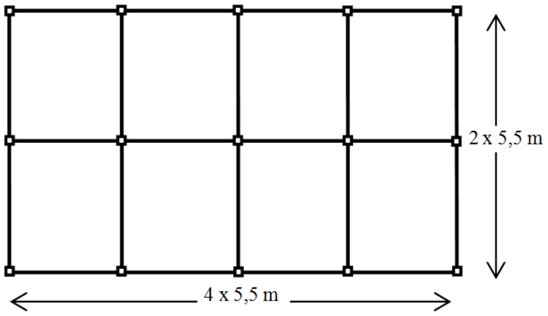

Fig. 1: Geometry of Structure

Table 1: Size of beam and column

Type	Width (mm)	Height (mm)
Beam 1	300	500
Beam 2	250	400
Column	400	400

2.2. Non-Linear Static Analysis

Pushover analysis consists of the increasing lateral loads representing an earthquake load until a structure achieves the target displacement (FEMA 356, 2000) [7]. The behaviour of the structure is obtained by a force-displacement curve that shows in Figure 2. Point A in this curve is the origin. Point B is the yielding point. B-C represents the strain-hardening areas the point corresponding to the maximum force and DE is the post-failure capacity region. Besides, FEMA 356 and ATC-40 are divided BC line to the 3 performance levels, so, these points describe structure performance as the first point [8].

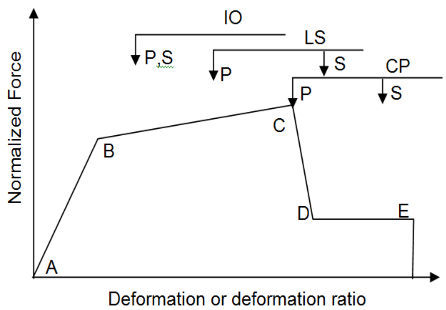

Fig.2: Idealized force-deformation curve

2.3. Modelling

Model structure of BTN is shown in figure 3. The slab load composed of self-weight and superimposed load (D) and 0.30 of the live load (L), where superimposed load 1.50 kN/m2, and live load = 2.50 kN/m^2 for all story. For roof D = self-weight + 1.00 kN/m2, and live load= 1.00 kN/m^2, respectively. The centre of the mass of the building is calculated based on mass distribution at each node. The earthquake design load is calculated based on Indonesian code (SNI 1726 2012) use equivalent static load. Site class is SD (medium soil). Building importance coefficient (I) equal to 1.0. The structure system of this building is Special Moment Resistance Frame System. The accidental eccentricity is ignored in the earthquake loading to observe the lateral load effect on the walls directly. ETABS version 9.00 finite element software is utilised for three-dimensional modelling and analyses of this building structure.

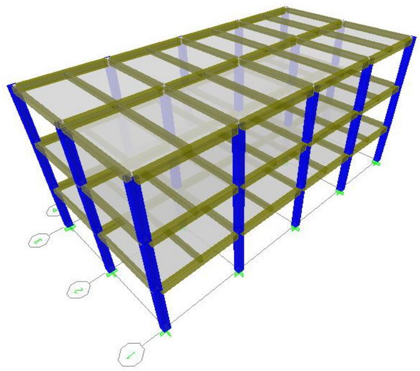

Fig. 3: Model structure of BTN office building Madiun

SNI 1726 2012 requires that the base shear, V, is to be calculated from the following formula[9]:

$$V = C_s . W$$

where, Cs is the coefficient of earthquake response, W is the total weight of the building, V is total design lateral force or shear at the base. V = 324.56 KN.

The base shear force is distributed as a lateral force which affects the joint at each story level of the building.

$$F_x = C_{vx} . V$$

$$C_{vx} = \frac{w_x . h_x^k}{\sum_{i=1}^{n} w_i . h_i^k}$$

The distribution of the lateral earthquake loads along the height of the building is shown in table 2 below.

Table 2: Lateral load distribution with heights

Story Level	Wi (KN)	Hi (m)	$W_i.h_i^k$	Cvx	Fi (KN)
3	933	12	10342.30	0.362	117.36
2	1614	8	12082.82	0.422	137.11
1	1614	4	6176.56	0.216	70.09
	4161		28601.68		324.56

2.4. Define and Assign Hinge Properties

Define non-linear force-displacement and moment-rotation behavior use frame non-linear properties that be assigned to discrete locations along all frame. These nonlinear hinges are rigid and do not affect the linear behaviour of the frame element[6].
Types of hinge properties can use Default hinge property or User-defined hinge property available with ETABS software. For assigning beam frame use default V2 and M3 hinges, and for assigning column use default P-M-M hinges .

2.5. Define Static Pushover

Pushover analysis is an available feature with ETABS software. For pushover analysis first, apply the gravity loading as GRAV shown in figure 4 and subsequently use lateral force as PUSH 2 in sequence to derive capacity curve and demand curve (as shown in figure 5). Start from previous pushover case as GRAV for gravity loads is considered for lateral loading as PUSH2. Push. to disp. magnitude fill with 0.48.

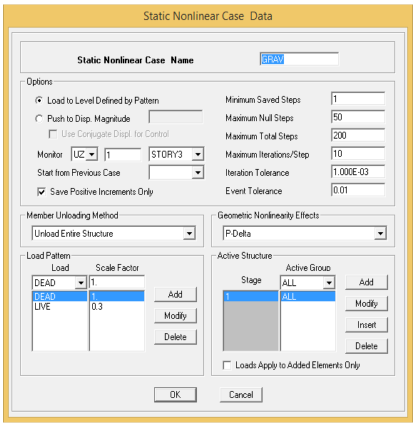

Fig.4: Static Nonlinear Case Data– GRAV

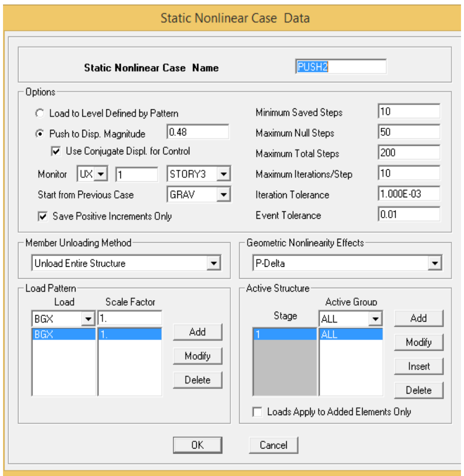

Fig.5: Static Nonlinear Case Data– PUSH2

3. Results and Discussion

After running analysis will be obtained the pushover curve that can be shown in fig 6. The response spectrum curve for damping ratios values 0.05, 0.1, 0.15 and 0.2 shown in red curve. In fig. 6 also show capacity curve, demand curve and value of performance point.
At the performance point known value of base shear 1089 KN, and the maximum displacement at corresponding roof is 127 mm. Base shear at performance point bigger than base shear force from earthquake load 324.56 KN.

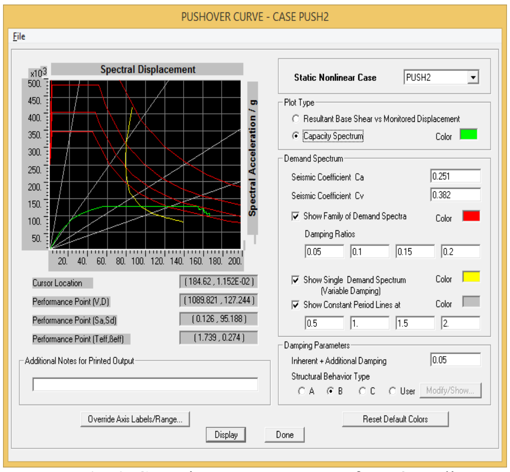

Fig.6: Capacity spectrum curve for EQ-X dir

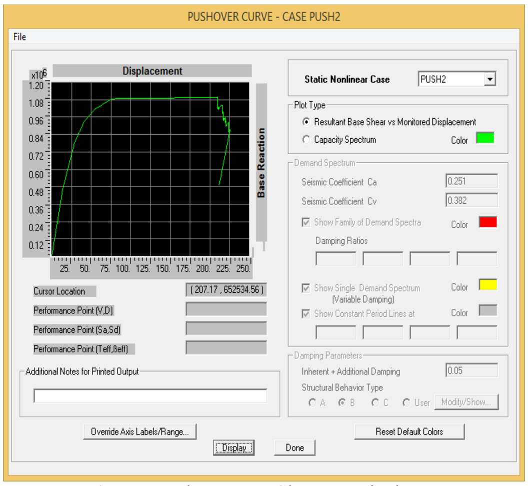

Fig.7: Resultant Base Shear vs Displacement

PUSHOVER CURVE

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	448	2	0	0	0	0	0	0	450
1	13.6342	463.0452	415	35	0	0	0	0	0	0	450
2	28.8036	786.8955	396	54	0	0	0	0	0	0	450
3	40.6573	927.0639	383	62	5	0	0	0	0	0	450
4	53.9269	1014.5604	368	54	28	0	0	0	0	0	450
5	73.3541	1079.5780	366	49	35	0	0	0	0	0	450
6	77.1356	1084.8508	363	52	35	0	0	0	0	0	450
7	82.7940	1087.4889	363	3	52	32	0	0	0	0	450
8	130.7940	1090.0074	363	0	3	84	0	0	0	0	450
9	178.7940	1092.5260	363	0	0	84	0	3	0	0	450
10	209.6827	1094.1466	363	0	0	84	0	0	3	0	450
11	209.6875	1017.9553	363	0	0	82	0	2	3	0	450
12	210.5576	1028.7660	363	0	0	82	0	0	5	0	450
13	210.5624	1011.4046	363	0	0	82	0	0	5	0	450
14	212.5721	1029.0922	363	0	0	82	0	0	5	0	450
15	213.5718	1034.5850	363	0	0	82	0	0	5	0	450
16	215.1059	1039.4532	363	0	0	80	0	2	5	0	450
17	215.8830	1040.3622	363	0	0	80	0	0	7	0	450
18	215.8878	986.5487	363	0	0	78	0	2	7	0	450
19	216.8557	997.3936	363	0	0	78	0	0	9	0	450
20	216.8605	942.5375	363	0	0	77	0	1	9	0	450
21	217.5821	950.9692	363	0	0	77	0	0	10	0	450
22	217.5869	935.0121	363	0	0	76	0	1	10	0	450
23	219.6327	957.2408	363	0	0	76	0	0	11	0	450
24	219.6375	925.7927	363	0	0	75	0	1	11	0	450
25	220.2603	932.8512	363	0	0	75	0	0	12	0	450
26	220.2651	895.5869	363	0	0	75	0	0	12	0	450
27	223.0255	919.4891	363	0	0	71	0	4	12	0	450
28	223.7828	923.6080	363	0	0	71	0	0	16	0	450
29	223.7876	859.8965	363	0	0	69	0	2	16	0	450
30	225.2846	874.7165	363	0	0	69	0	0	18	0	450
31	211.8368	488.7092	450	0	0	0	0	0	0	0	450

Fig. 8: Plastic hinge pattern for PUSH2

The pushover analysis was including 31 steps. Fig. 7 shown resultant base shear vs displacement. Then fig. 8 shown plastic hinge pattern for pushover curve analysis, base shear and displacement of each step and number of hinges in each step and its distribution in each state (B-IO, IO-LS, LS-CP, CP-C, C-D, D-E, and E). The ultimate base shear (at step 10) is 1094 KN. The maximum displacement (at step 30) is 225 mm. At performance point where demand and capacity meet, 363 hinges are in AB stage, 0 in B-O stages, 3 are in IO-LS, and 84 hinges are in LS-CP stages. Then can be concluded the overall performance of this building is said to be Life Safety (LS) to Collapse Prevention (CP).

4. Conclussion

The performance level of BTN office building can be analysed by pushover analysis using ETABS 9.0 software. From analysis indicate that the maximum base shear can be done at the structure is around 1094 KN.The maximum lateral deformations are 225 mm (within the target displacement of the structure).The performance level of BTN office Building including Life Safety to Collapse Prevention (LS - CP). Building designed refer to SNI

1726 2012 found to have better performance level under given earthquake loading.

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