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Comparison of Strength and Performance Based Designs for Buildings of Different Heights and Area Width

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ABSTRACT

Performance Based Design (PBD) planning can estimate the ability of a structure to withstand earthquakes according to desired performance. The purpose of this study is to examine more efficient methods between Strength Based Design (SBD) and PBD based on the value of the Budget Plan. An analysis was carried out on 3 building models with heights of 4 floors (16 m), 8 floors (32 m), and 12 floors (48 m) with a height and width ratio of the building being 2:1. The dimensions of each building being 8 m x 8 m, 12 m x 12 m, 16 m x 16 m. All models are planned to achieve safety performance limits based on the different PBD Dimensions. Adjustments are done by increasing or reducing 5 cm dimensions in each column to meet the displacement requirements. The results show that all three models reached the maximum allowable displacement of 80 mm. The obtained budget plan shows a difference of -10% of SBD meaning that PBD is not efficient in a 4-storey building (low rise building). While in the 8-storey building (middle rise building) and the 12 storey (high rise building) the difference in the budget plan is 3% and 18% respectively, explaining the efficiency of Performance Based Design.

Key words: Reinforcement, Strength Based Design, Performance Based Design, Displacement, and Budget Plan.

1. INTRODUCTION

There are many earthquake prone areas in the world and the Indonesian archipelago is one of them. Attempts to match building construction to seismic activity is a development aimed at finding solutions to earthquake problems in building construction. Buildings are designed to withstand earthquakes with a performance-based concept or better known as Performance Based Design (PBD), which sets a Performance Level expected to be achieved when a structure is hit by an earthquake of a certain intensity.

There are two elements in determining the level of PBD performance, namely demand and capacity. Demand is the representation of earthquake ground motion, while capacity is a representation of a structure's ability to resist demand [1].

Meanwhile the regulations in force for Indonesia, namely: Indonesian National Standards are based on the Strength Based Design (SBD) method, where each structure must be planned with the ability to withstand the basic shear loads due to earthquakes.

Based on previous research by Wahyuni et al [2], SBD is effective in eight storey buildings, but for buildings of 12 to 16 floors PBD is more effective. Then in a study by Wantalangie et al [3], displacement and base shear with equivalent lateral force analysis is always greater than the response spectrum variance analysis in models of 5, 10 and 15 floors.

From this research the difference in building height is often an experiment to find out which planning methods are effective and efficient, but little attention is paid to the width and the building area by taking into account the conditions and regulations of the local authorities.

Therefore, a comparative analysis of the SBD and PBD methods will go a long way in providing building planners an overview into considering the effect of buildings' height and area on the behaviour of reinforced concrete structures in earthquake prone areas, and to what extent the method is considered more efficient.

2. RESEARCH METHOD

This study conducted a comparative analysis of the SBD and PBD methods. Structural modelling using the Extended Three-Dimensional Analysis of Building System (ETABS 2013) program, and the open frame structure modelling (Table 1) with the Special Moment Frame Structure (RSPMK) system and was carried out.

RSPK is a spatial frame system in which structural components and their joints resist forces acting through flexural, sliding and axial actions [4]. The selection of structures based on structural system restrictions and height restrictions is the D seismic design category with heights up to 72 m (SNI-1726-2012 article 7.2.5.4).

There were three SBD and PBD building models that were experimented on, each building presented a height classification based on SNI-1726-2002.

Table 1: Details of structural Modelling

Model	No. of Floors	Height	Width	Comparison
1	4	16 m	8	2:1
2	8	32 m	16	2:1
3	12	48 m	24	2:1

The height of the building is planned with three variations, namely 4 floors, 8 floors and 12 floors. The reason is because it is a consideration of the Indonesian Ministry of Public Works Regulation Number: 29 / Prt / M / 2006 concerning Guidelines for Technical Requirements for Buildings.

In general, buildings are said to be low-rise if the height is less than 35 meters and said to be high-rise if the more than 35 meters [5].

The height of the building structure is measured from the lateral clamping level of not more than 10 levels or 40 m (SNI-1726-2002). The author's classification however is based on height including: 1. Low Rise Buildings consisting of 4 floors; 2. Medium Rise Buildings consisting of 8 floors; and 3. Low Rise Building consists of 12 floors.

The building area is planned with a ratio of structure height to width by 2:1, this is to prevent the span of the beam from being changed, which is still 4 meters on the X and Y axes.

Structural analysis of the SBD method using the ETABS Structure Analysis Program to obtain the internal forces that were used in detailing elements according to SNI 03-2847-2013.

Dynamic analysis for the design of earthquake resistant structures is carried out if a more accurate evaluation of the earthquake forces acting on the structure is needed, and to determine the behaviour of the structure due to earthquake effects [6].

The PBD method structure analysis uses pushover thrust load, an analysis that can describe a performance-based planning [7]. Thrust load is done by determining the control point on the roof top. The structure is then driven by earthquake load gradually until the building reaches safety performance.

The performance level of a building can be assessed based on the planned earthquake, so that the building owner can choose the level of performance of the building [8]. To achieve safety performance, adjustments are made by adding or reducing Dimensions of 5 cm in each column to meet displacement requirements and not over stressing.

According to Muljati [9], the PBD method has been successful in protecting structures from failure during unsafe mechanisms that cause over stressing which results in displacement between floors of a building. Whereas in other studies, it also noted that to optimize the strength of columns, an additional Dimension of 20% should be carried out for lower floors and for upper floors to be reduced by 25% [10].

The purpose of pushover analysis is to estimate the maximum force and deformation that occurs and to obtain information on which parts are critical. The following Figure 1 is an illustration of the research flow:

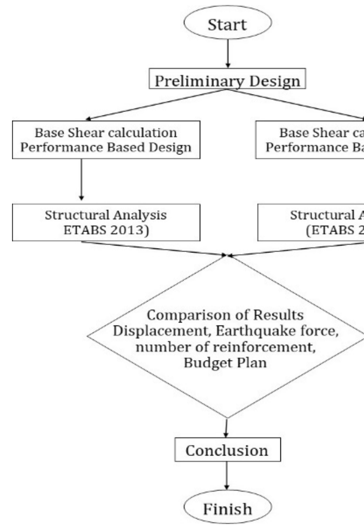

Figure 1: Research Flow Chart

Displacement targets or building performance points are obtained by the capacity spectrum method that has been built in the ETABS program. Whereas to get a performance point and evaluate it, a method found in the FEMA 356 seismic analysis technique is used.

The quantity of the reinforcement (columns and beams) is obtained and the analysis of the main structure is carried out as a limitation and then comparing the results of the analysis of the Strength Based Design and the Performance Based Design, to ascertain which method is more efficient.

3.RESEARCH METHOD

The planned building includes the Seismic Design Category D with building risk category II. From the ETABS analysis it was obtained that the X-direction mass participation was 95% in the 5th mode and the Y-direction mass participation was 95% in the 5th mode. It fulfilled the requirements stipulated in SNI 1726-2012 article 7.9.1 where the least combined mass diversity participation is 90%.

Structural design control was carried out to check the crossing boundary between floors as is also regulated in the Indonesian National Construction Standards (SNI) 1726-2012, articles 7.8.6 and 7.12.1. The conditions are Δ allowable > Δi and $\Delta i = \delta * Cd / Ie = 10.45 < \Delta$ allowable = 80 mm. Then these requirements have been fulfilled.

The relationship between static and dynamic earthquake base in the SNI 1726-2012 regulation on dynamic earthquake cannot be less than 85% static earthquake load, or in other words $V_{dynamic} \geq 0.85\ V_{static}$. Since the obtained earthquake X direction: Dynamic = 28410 kg ≥ 85% V_{static} = 6314 kg, the Y direction earthquake: $V_{dynamic}$ = 28878 kg ≥ 85%, and V_{static} = 6314 kg, then these requirements are fulfilled, so planning using the strength-based design method can be calculated.

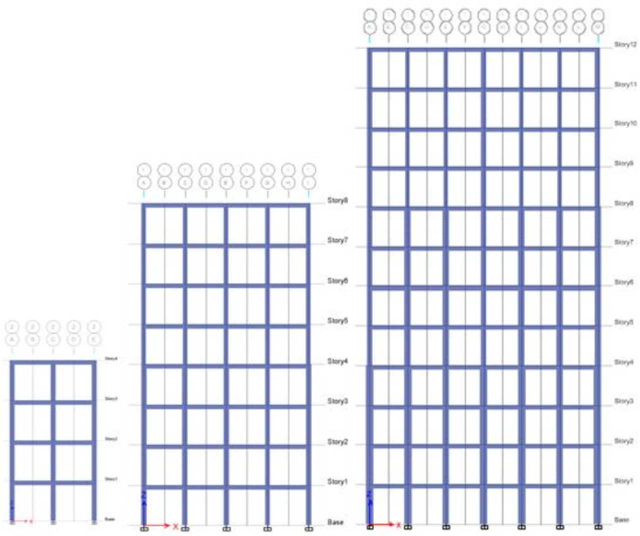

Figure 2: Modelling 4, 8 and 12 storey buildings

Displacement in storey buildings is an important requirement for structural and non-structural damage to buildings at various earthquake levels [11] (Chaudhari and Dhoot 2016). Below is a displacement comparison of 4, 8 and 12 storey buildings (Table 2)

. **Table 2:** Displacement Comparison of a 4 Storey Building

Floors	Height (mm)	Δi (mm) SBD	Δi (mm) PBD	Allowable (mm)
4	4000	10.45	24,20	80
3	4000	17.05	43.45	80
2	4000	22.00	59.95	80
1	4000	15.95	46.20	80

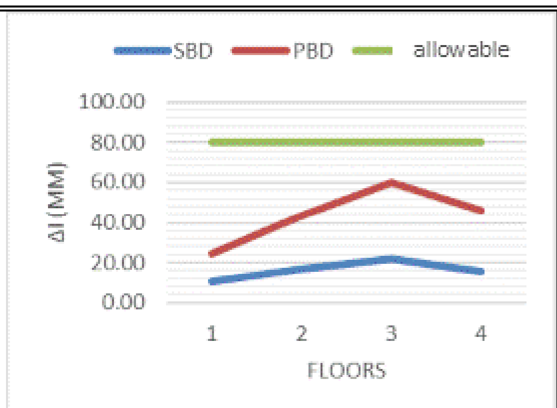

Figure 3: Displacement Comparison of a 4 Storey Building

Table 3: Displacement Comparison of an 8 Storey Building

Floors	Height (mm)	Δi (mm) SBD	Δi (mm) PBD	Δallowable (mm)
8	4000	6.60	0.55	80
7	4000	11.00	1.10	80
6	4000	14.30	1.65	80
5	4000	15.95	2.20	80
4	4000	18.70	1.65	80
3	4000	21.45	2.20	80
2	4000	28.05	3.30	80
1	4000	22.00	2.20	80

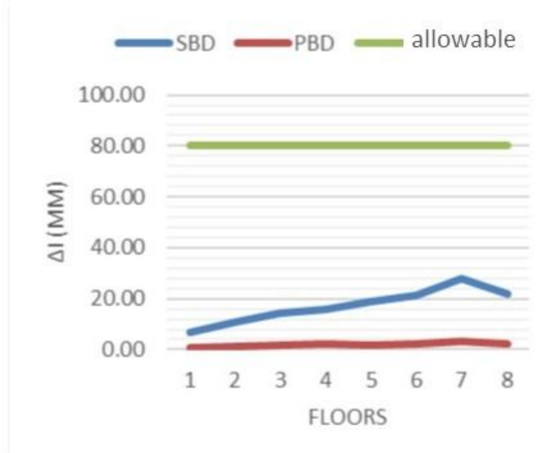

Figure 4: Displacement Comparison of an 8 Storey Building

Table 4: Displacement Comparison of a 12 Storey Building

Floors	Height (mm)	Δi (mm) SBD	Δi (mm) PBD	Δallowable (mm)
12	4000	8.80	1.65	80
11	4000	9.90	2.75	80
10	4000	10,45	2.75	80
9	4000	11.00	2.75	80
8	4000	11.55	2.20	80
7	4000	12.10	2.75	80
6	4000	13,20	2.75	80
5	4000	13.75	3.30	80
4	4000	15.40	3.30	80
3	4000	17.60	3.30	80
2	4000	17.60	4.40	80
1	4000	9.90	2.20	80

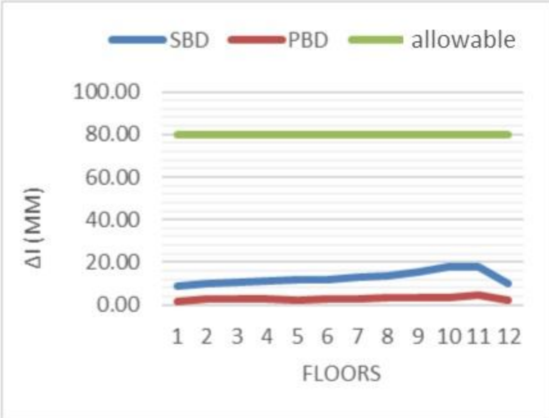

Figure 5: Displacement Comparison of 12 storey building

Table 3 and 4 with the corresponding Figure 4 and 5 respectively, show that the PBD displacement for buildings of 8 and 12 floors is very small due to elastic displacement which is calculated due to earthquake force design strength levels between floors.
It is also seen in Table 4 that the SBD and PBD methods meet the permitted displacement requirements, which are less than 80 mm and do not over stress. But more efficient for a 4-story building (Low Rise Building) is using the SBD method while in the 8-story building (Medium Rise Building) and 12 floors (High Rise Building) using the PBD method.

Earthquake Force Distribution Analysis of 4, 8 and 12 Storey Buildings

Table 5: Comparison of Earthquake Force Distribution in 4-storey buildings

Floors	Weight (KgF)		Weight (KgF)	
	SBD	PBD	SBD	PBD
4	123565	127155	7428	7795
3	264647	275935	5656	6419
2	405728	424715	8671	9879
1	546810	573495	11687	1334 0

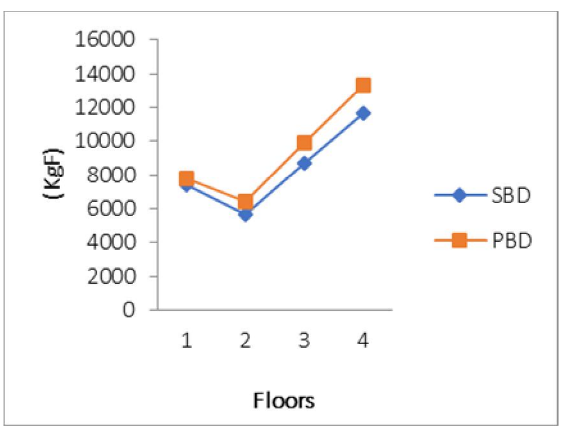

Figure 6: Comparison of 4 Floor Building Style Distribution

Table 6: Earthquake Force Distribution Comparison on an 8 Storey Building

Floors	Weight (KgF)		Weight (KgF)	
	SBD	PBD	SBD	PBD
8	163088	106481	2534	1556
7	347534	276108	5001	3656
6	531980	445735	7007	5267
5	716426	615362	8499	6356
4	900872	788122	9402	6905
3	1085318	964535	9603	6834
2	1269763	1140947	8902	5993
2	1454209	1317359	6848	4148

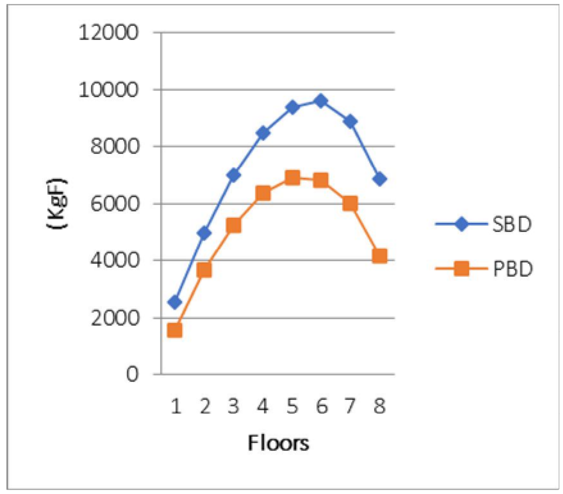

Figure 7: Comparison of the 8 Floor Building Style Distribution

Table 7: Comparison of Earthquake forces Distribution for 12 storey Building

Floors	Weight (KgF)		Weight (KgF)	
	SBD	PBD	SBD	PBD
12	228359	186695	2975	2572
11	606048	475866	7365	6131
10	983736	765036	11077	9160
9	1361425	1054207	14091	11640
8	1739113	1361506	16381	13732
7	2116802	1689529	17919	15377
6	2494490	2017552	18666	16310
5	2872179	2345576	18576	16481
4	3249867	2688688	17582	15913
3	3627556	3048620	15591	14462
2	4005244	3408552	12445	11838
2	4382933	3768484	7822	7681

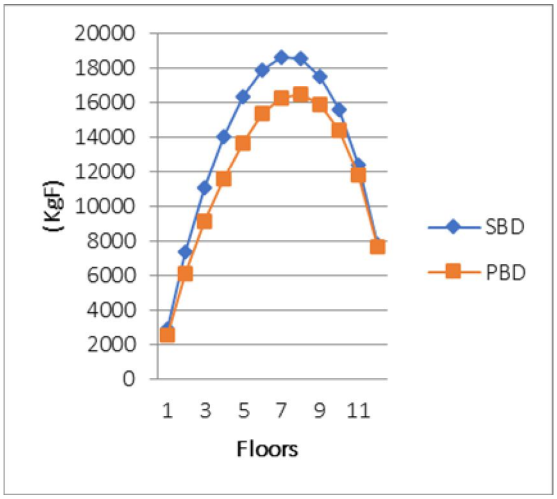

Figure 8: Comparison of Distribution Style for an 8 storey Building

Table 8: Comparison of Earthquake Forces Distribution Per Floor

Building	SBD (KgF)	PBD (KgF)
4 Floors	33443	37433
8 Floors	34755	23879
12 Floors	53440	49894

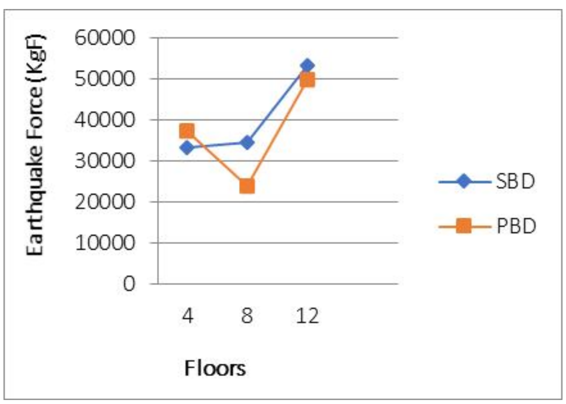

Figure 9: Comparison of Style Distribution Per Floor

The results in Table 8 and Figure 9 above shows that the more efficient method of designing the 4 storey building is the SBD method because the earthquake force magnitude is lower, while for the 8 and 12 storey buildings the most efficient method of design is the PBD method because the magnitude of the earthquake force is lower than when the SBD is used. This is also supported by the results in Karimzada [12], that earthquake forces in buildings of 8 and 12 floors are better handled with the use the PBD method compared to the Time History method.

In another study, it is also noted that the PBD method of reinforced concrete structures is able to predict building performance with good accuracy [13].

Analysis of Building Reinforcement

The reinforcement Dimensions in the building blocks of buildings with 4, 8 and 12 floors are the same, while the Dimensions of the columns are different. Tables 9,10 and 11 below present a comparison of the number of reinforcement columns and column Area.

Table 9: Column Reinforcement for a 4 Storey Building

	Reinforcement	SBD Floors 1-4	PBD Floors 1-4
Dimension		45 x 45	50 x 50
Pedestal	D18	12	16
Area	D18	12	16

Table 10: Column Reinforcement for an 8 Storey Building

	Reinforcement	SBD Floors 1-4	PBD Floors 1-4
Dimension		50 x 50	50 x 50
Pedestal	D18	16	16
Area	D18	16	16
	Reinforcement	Floors 5-8	Floors 5-8
Dimension		50 x 50	45 x 45
Pedestal	D18	16	12
Area	D18	16	12

Table 11: Column Reinforcement for a12 storey building

	Reinforcement	SBD Floors 1-4	PBD Floors 1-4
Dimension		80 x 80	75 x 75
Pedestal	D25	20	18
Area	D25	20	18
	Reinforcement	Floors 5-8	Floors 5-8
Dimension		80 x 80	65 x 65
Pedestal	D25	20	14
Area	D25	20	14
	Reinforcement	Floors 9-12	Floors 9-12
Dimension		80 x 80	50 x 50
Pedestal	D25	20	8
Area	D25	20	8

As seen from the Table 9 above, the analysis of the 4 storey building shows that the more efficient method of design is the SBD method because the reinforcement needed is less than in the PBD method, whereas in the 8-story and 12-storey building the most efficient method is the PBD method because the reinforcement needed is less compared to using the SBD method.

The results of this reinforcement are in line with the results a research by Arasy et al [14] that buildings designed at the Maximum Considered Earthquake (MCE) spectra with the PBD safety performance level can reduce column size by 30% and the reinforcement by 1% for all columns.

Budget Plan Analysis

A comparative analysis of the SBD and PBD methods to structure (Beam and Column) cost budget plan for 4, 8 and 12 storey buildings can be seen in Table 12.

Table 12: Budget plan Comparison in Indonesian Rupiah

(Floors)	SBD (Million)	PBD (Million)	Difference (Million)	Percentage
4	507	560	- 53	-10%
8	3.313	3.225	88	3%
12	14.888	12.270	2.618	18%

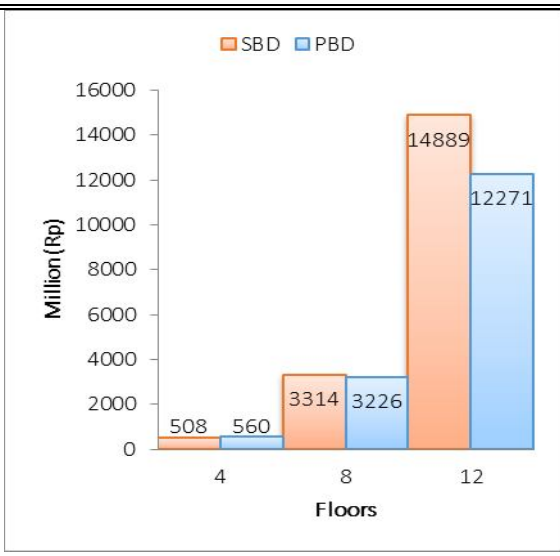

Figure 10: Budget plan Comparison for 4, 8 and 12 floor buildings

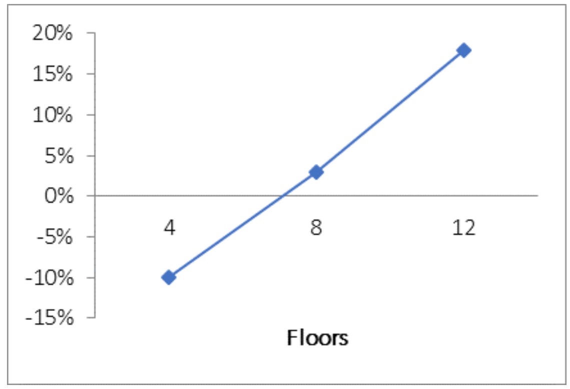

Figure 11: Comparison of difference in budget plan for 4, 8 and 12 storey buildings

It can be seen from Figure 10 that the budget plan the 4-storey building designed with the PBD method is more expensive, whereas the budget of the SBD method is cheaper with a budget reduction of 10% between the two methods. But for the 8 and 12 storey buildings, it is the opposite of the 4-story building, the budget produced by the SBD method is higher by 3% and 18% respectively, making the PBD method budget cheaper. This means that in the Low-Rise Buildings like a 4-storey building, the more efficient design method is the Strength Based Design, whereas the most efficient design method in Medium Rise buildings and High-Rise buildings is the Performance Based Design.

4. CONCLUSION

Both designs are made with safety in mind as it always is in all construction projects. Performance Based Design is crafted notably with different column dimensions after every 4 floors in 8 and 12 storey buildings. Whereas the Strength Based Design is designed maintaining the same column dimensions as these dimensions may only change after 4 floors, which is not applicable in a building of only 4 floors.

The earthquake force presented differently on both designs; the SBD method in Hight Rise Building experiences greater force than the PBD method so the SBD requires more reinforcement for such buildings. The resulting budget has a price reduction of 10% in the 4 storey, and price increase of 3% and 18% for the 8 and 12 storey buildings respectively.

With comparison in building height and width at a ratio of 2:1, the new Performance Based Design shows its efficiency in the High-Rise Building, which can be seen in the budget difference percentages in Table 12. The more effective and efficient design method in Low Rise Buildings i.e. 4-storey buildings is the Strength Based Design method while in Medium and High Rise Building it is the Performance Based Design.

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