5. Static and Dynamic Story Shear in Split-Level Building on Sloping Ground

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Static and Dynamic Story Shear in Split-Level Building on Sloping Ground

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Abstract. Building structures located on slopes behave differently than structures located on flat ground because of the different levels of stepped floors made to overcome the slope of the land, resulting in several layers of basements. Also, due to the existence of these steps and the difference in soil level, a retaining wall is often made to hold the soil. The forces acting on the structure consist of those acting on the structure and those acting on the retaining walls, both against gravity loads and against earthquake loads. Often, there is an avalanche force due to the stability of the slopes. The main objective of this research is to: 1) Perform building modelling according to certain assumptions, 2) evaluate the distribution of story-shear forces based on a static and dynamic analysis of building structures, and 3) determine the scale factor based on the distribution of shear forces at the levels of static and dynamic analysis. This paper discusses the structure of a seven-story building with stepped floors, which is then used to calculate a similar structure with 14 levels. The dual system is used to overcome the effect of a smaller floor area on the lower part of the terraces due to the slope of the ground. In this case study, the load due to lateral earth pressure is calculated separately from the building structure with the assumption that the retaining wall, namely the soldier-pile type, can carry the lateral earth pressure as well as overcome sliding due to slope stability. Therefore, the building structure can be designed separately without considering the presence of lateral forces due to differences in soil levels. In the dynamic analysis of the response spectrum, it is advised to obtain a scale factor to compare the basic shear force with the basic shears force of the static analysis. In conclusion, the results of the static and dynamic analysis showed the distribution of the story-shear forces from the first to seventh floors as smaller than those of the eighth floor. Static analysis with ETABS software provides a more rational shear-force solution by level compared to manual static analysis, which assumes cumulative sum. Since the first through seventh floors are semi-basements, a scale factor was taken for the dynamic shear force to the static shear force at the eighth floor.

1 Introduction

Buildings are often built on slopes or sloping land because they have beautiful views. They are generally made of terraces following the slope of the land by providing a retaining wall to withstand the difference in soil between the floors. Structural modelling to calculate building loads and earthquake forces as well as earth pressure needs to be undertaken, whether modelled as a whole or separately [1–3]. Modelled as a whole, the structure of the building and its retaining wall are represented as a single unit that receives gravity loads as well as earthquakes and soil pressure. In this research, modelling of the structure is carried out separately. The soil pressure is resisted by a retaining wall in the form of a soldier pile that also keeps the soil from sliding due to slope stability. Thus, the building structure is calculated independent of earth pressure. In relation to the soil conditions, the building has pedestals with different levels where the floor mass at the bottom is less than the floor mass at the top, which will exhibit different structural behavior than when the pedestal is placed on a flat plane. The building against the sloping ground is due to the placement of the columns that are not on one flat plane but are located at different levels due to the sloping ground.

The uniqueness of a building structure on a slope lies in the shape of the floor area at the bottom attached to the ground that is smaller than the floor area at the top that is also attached to the ground. So, the part that is attached to the ground has several floors because of the slope of the land made into terraces. This results in unusual structural behavior. When a dynamic analysis is carried out and the dynamic-base shear force is compared with the static-base shear force, it is difficult to determine the scale factor. Buildings that are on flat ground generally take the scale factor at level one to compare the dynamic-base shear force with the static-base shear force because at level one the building is no longer attached to the ground. Buildings located on sloping ground made of terraces may still be attached to the ground above the first level, resulting in a small dynamic-base shear force, causing a large-scale impact. Here, floors that are not attached to the ground are still used so that a rigid diaphragm is not made for floors that are attached to the ground, therefore the results are similar to those of the static-base shear force [4, 5]. The

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*Corresponding author: daud.rw@eng.maranatha.edu goal is to use a rigid-diaphragm floor for a floor that is no longer attached to the ground for the dynamic analysis [6, 7]. This can be achieved by providing a separate support for the lateral force caused by the soil pressing against the retaining wall, allowing the structure to vibrate freely without additional soil pressure. In this case, the details of the structure need to be adjusted so that the structure can act without the influence of soil pressure that is retained by the retaining wall, which also functions to resist landslides due to slope stability. Separate modelling allows soldier piles to be designed as cantilever beams that resist soil pressure and earthquakes. Soldier piles also prevent the soil from sliding due to the slope of the ground. In front of the soldier pile, a concrete wall holds back the soil and water from the soldier-pile gap, which blends in with the columns and slabs of the basement above the soldier pile [8, 9].

2 Analytical Model

The building model in this study was assembled using a 3D structural model for a 13-story reinforced-concrete building with a frame structure and shear walls using the ETABS computer program [10, 11]. The building was designed for use as a school. The original model structure is situated in Bandung City (S_{DS}=0.67g, S_{D1}=0.63g) and has an E site class. The material property of the concrete is f'_c = 28 MPa, and the steel reinforcement is f_y = 420 MPa for all element types in the building. The 3D-analytical model is shown in Figure 1, and the building and floor plans are shown in Table 1.

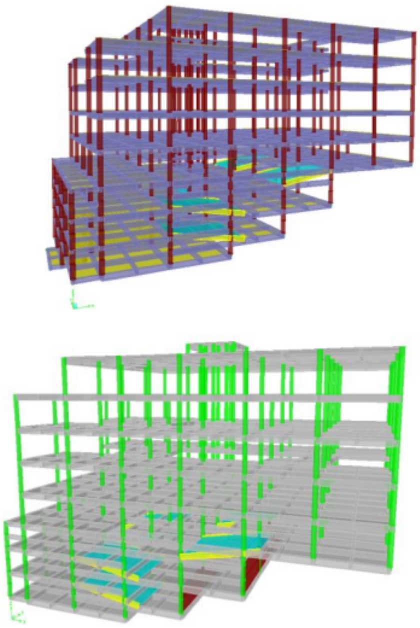
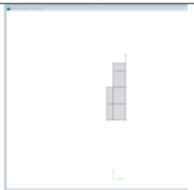
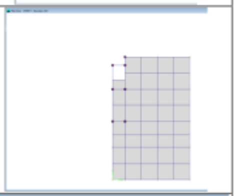
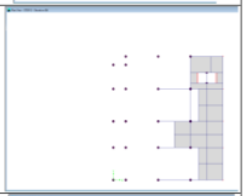
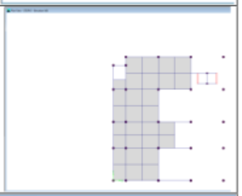
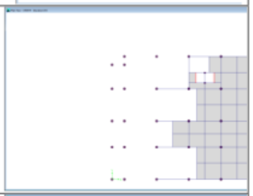
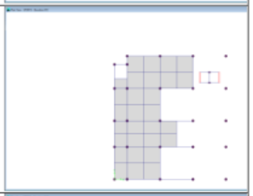
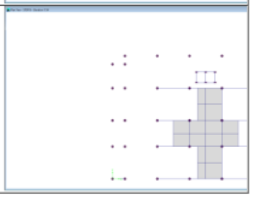
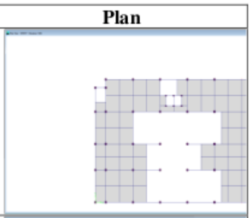
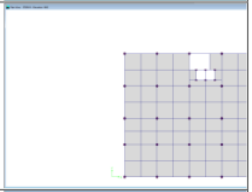
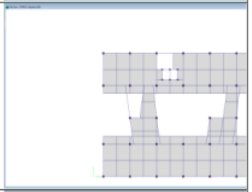
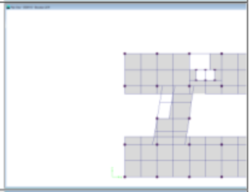
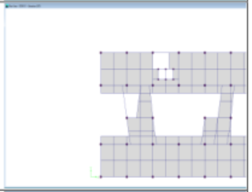
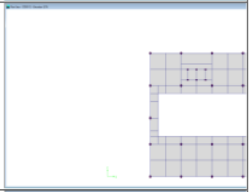
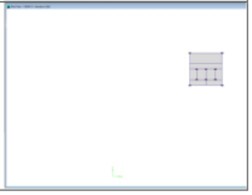


Fig. 1. 3D-analytical model for building with and without basement wall

The ground behind the split level is held up by soldier piles, while in front of the soldier pile, there is a basement wall that can be modelled based on the structure. Here, the distribution of static and dynamic story shear will be calculated for the two models.

Table 1. Building Floor Plan.

Floor	Plan
GF	
1st FL	
2nd FL	
3rd FL	
4th FL	
5th FL	
6th FL	

Floor	Plan
7th FL	
8th FL	
9th FL	
10th FL	
11th FL	
12th FL	
13th FL	

In the diagram of the structural modelling, the mass of the floor at the lower level is smaller than the mass of the floor at the level above. Based on the inspection results for horizontal and vertical irregularities, the structure still meets the requirements. Building-structure modelling is carried out separately with soil retention through soldier piles that are calculated separately and modelled as cantilever beams that resist the lateral force from the soil. It is assumed that the ground floor is floating such that the floor in front of the soldier pile merges with the floor behind the soldier pile that is attached to the ground.

3 Result and Discussion

The analysis of the dual-system structure gave the results shown in Fig. 2. The blue V_{sx} and V_{sy} graphs are the results of manual static analysis with ETABS software, while the red V_{sx} and V_{sy} are the results of manual static analysis with a value of 85% V_{sx} and V_{sy}. The purple V_{sx} and V_{sy} graphs are the results of static analysis with ETABS software. The distribution and values of the story-shear forces calculated manually are different than those calculated by ETABS software. The value of the static analysis level-shear force calculated manually is greater than the static analysis level-shear force from the software on the floor below. This is because mode one is dominant, but because it is still on the basement layer, what is calculated is the story-shear force on floor eight, which is no longer connected to land. The scale factor is taken from the sixth floor.

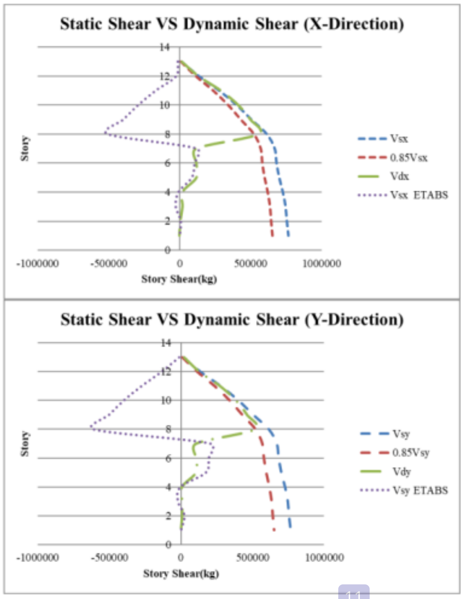


Fig. 2. Initial analysis of static and dynamic story shear in X-direction and Y-direction

The difference in signs/directions in ETABS software analysis and static analysis using the manual method is not a problem because the directions are the same. The manual method uses a cumulative-distribution story-shear, but dynamic analysis does not, which accounts for their value differences. The distribution of the shear force in static analysis and dynamic analysis gives a small value at levels one to seven and then grows to a value that is almost the same as the static-shear force at level eight in both the X and Y directions. When using the scale factor on the first through seventh floors, which is based on manual static analysis, the dynamic shear force will be much greater on the eighth floor. This is not necessary because by looking at the distribution of shear forces for static analysis with ETABS software and the distribution of shear forces for dynamic analysis, it can be seen that the models are similar. In conclusion, the distribution of static- and dynamic-level shear forces given by the software is more precise than that given by the manual method for static-level shear forces.

Table. 2. Story shear comparison on building without basement wall model in X-Direction

Story	V_{dx}(kg)	$0.85V_{sx}$	$0.85V_{sx} \geq V_{dx}$
13	16820	11389	OK
12	134426	21763	OK
11	292188	143524	OK
10	414349	248747	OK
9	499868	336988	OK
8	558011	428761	OK
7	119169	99135	OK
6	119634	88338	OK
5	120041	72065	OK
4	21769	7678	OK
3	21830	23944	CHECK
2	6880	6005	OK
1	283	99	OK

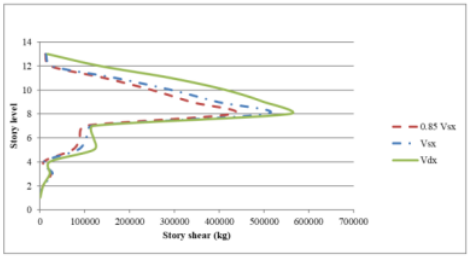


Fig. 3. Final analysis of static and dynamic story shear in X-direction without basement wall

Table. 3. Story shear comparison on building without basement wall model in Y-Direction

Story	V_{dy}(kg)	$0.85V_{sy}$	$0.85V_{sy} \geq V_{dy}$
13	23135.08	11389.15	OK
12	129962.44	115262.55	OK
11	274717.45	234675.574	OK
10	385145.09	339956.565	OK
9	463129.78	427791.774	OK
8	519548.77	519565.424	CHECK
7	106364.16	175221.168	CHECK
6	106289.5	164423.618	CHECK
5	106407.7	148150.368	CHECK
4	8640.71	2304.197	OK
3	8681.79	18569.797	CHECK
2	8961.5	20183.8195	CHECK
1	270.59	343.264	CHECK

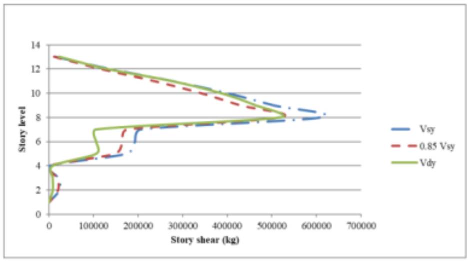


Fig. 4. Final analysis of static and dynamic story shear in Y-direction without basement wall

Table. 4. Story shear comparison on building with basement wall model in X-Direction

Story	V_{dx}(kg)	$0.85V_{sx}$	$0.85V_{sx} \geq V_{dx}$
13	15745.84	11389.15	OK
12	125462.74	21762.55	OK
11	272734.42	143524.2	OK
10	386746.62	248746.55	OK
9	466569	336987.6	OK
8	520785.1	428761.25	OK
7	113911.9	99135.3725	OK
6	114358.63	88337.8225	OK
5	114738.75	72064.5725	OK
4	21186.76	7677.931	OK
3	21239.87	23943.531	CHECK
2	4453.12	6004.689	CHECK
1	227.74	99.3395	OK

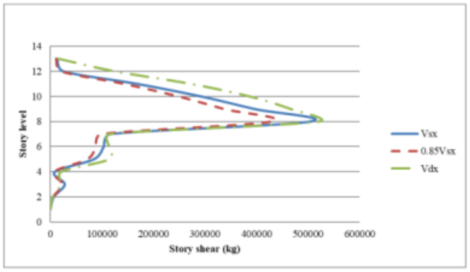


Fig. 5. Final analysis of static and dynamic story shear in X-direction with basement wall

Table. 5. Story shear comparison on building with basement wall model in Y-Direction

Story	V_{dy}(kg)	$0.85V_{sy}$	$0.85V_{sy} \geq V_{dy}$
13	23336.59	11389.15	OK
12	130958.14	115262.55	OK
11	276810.15	234675.574	OK

Story	V_{dy}(kg)	$0.85V_{sy}$	$0.85V_{sy} \geq V_{dy}$
10	388154.37	339956.565	OK
9	466243.04	427791.774	OK
8	522381.09	519565.424	OK
7	35536.01	175221.168	CHECK
6	35519.2	164423.618	CHECK
5	35565.39	148150.368	CHECK
4	10396.13	2304.197	OK
3	10406.73	18569.797	CHECK
2	16487.63	20183.8195	CHECK
1	261.39	343.264	CHECK

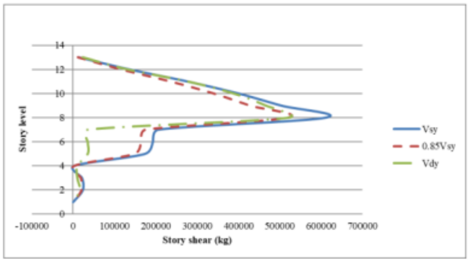


Fig. 6. Final analysis of static and dynamic story shear in Y-direction with basement wall

Table. 6. Story shear comparison on building with basement wall and Soldier Pile model in X-Direction

Story	V_{dx}(kg)	$0.85V_{sx}$	$0.85V_{sx} \geq V_{dx}$
13	13399	11389	OK
12	25603	21763	OK
11	168852	143524	OK
10	292643	248747	OK
9	396456	336988	OK
8	504425	428761	OK
7	116630	99135	OK
6	103927	88338	CHECK
5	84782	72065	CHECK
4	9033	7678	OK
3	28169	23944	CHECK
2	7064	6005	CHECK
1	117	99	CHECK

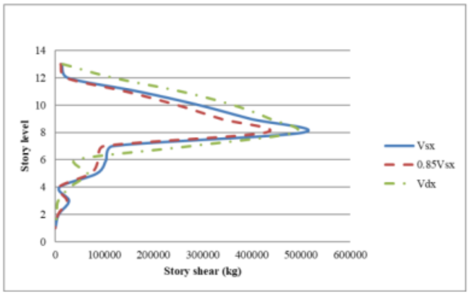


Fig. 7. Final analysis of static and dynamic story shear in X-direction with basement wall and soldier pile

Table. 7. Story shear comparison on building with basement wall and soldier pile model in Y-Direction

Story	V_{dy}(kg)	$0.85V_{sy}$	$0.85V_{sy} \geq V_{dy}$
13	13399	11389	OK
12	135603	115263	OK
11	276089	234676	OK
10	399949	339957	OK
9	503284	427792	OK
8	611253	519565	OK
7	206143	175221	OK
6	193440	164424	CHECK
5	174295	148150	CHECK
4	2711	2304	OK
3	21847	18570	CHECK
2	23746	20184	CHECK
1	404	343	OK

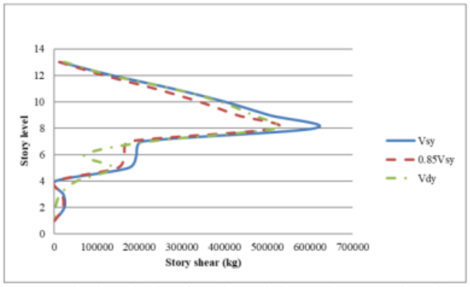


Fig. 8. Final analysis of static and dynamic story shear in Y-direction with basement wall and soldier pile

Fig. 3 compares the story-shear values for the static analysis using the ETABS software with the story-shear values for the dynamic analysis. The scale factor taken gives a satisfactory value on the eighth floor, while on the first through seventh floors, there is something that is slightly less, this is not a problem because these floors are semi-basement floors.

4 Conclusion

In conclusion:

1. Buildings built on sloping land with terraced structures / split levels have smaller floor areas on the terraced lower floors, namely floors one through seven, which function as semi-basement parking.
2. In the manual calculation, the static-equivalent analysis gave greater values on the floors below the terraces, namely floors one through seven because of the cumulative-sum assumption.
3. The software calculation of the equivalent static analysis gave more realistic values for the floors below the terraces, namely the first through seventh floors, according to the floor area, which had an impact on the floor mass.
4. The static equivalent analysis software calculation gave a negative value, while in manual calculations

it gave a positive value, which is not a problem because it is a sign agreement.

5. The basic shear force in static analysis was based on mode one, which has the largest mass and therefore was used as a reference for the scale factor in dynamic analysis.
6. The results of the basic shear-force dynamic analysis in the X direction on the first run provided a greater value than the results of the static analysis in the X direction on the first run, so for the dynamic shear force values in the X direction, this value can be taken.
7. When designing the lower structure, soldier piles for slope stability and retaining walls should be considered to manage gravity and earthquake loads.

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