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Investigating and improving the resistance of concrete structures against earthquakes (case study: Tabas fault, Iran)

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Abstract
Since Iran is one of the earthquake-prone regions in the world, paying attention to earthquakes should be one of the main goals of experts in construction. In the country of Iran, as a result of the convergence of sciences such as seismology, structural engineering and geotechnical engineering, the goal of improving the performance of structures against earthquakes and as a result increasing their durability and safety has been implemented in the code of design of buildings against earthquakes. In this research, the role of winged shear walls and their behavior in aftershocks applied to the structure and then the behavior of connections have been investigated. The results of the research show that with the increase of floors, the maximum amount of shear force distribution interval in the walls increases. Increasing the wing reduces the horizontal displacement of the wall, and by increasing the length of the wall, the drift decreases. With the increase in the height of the structure, the walls with 2-meter wings have been able to show relatively good behavior and reduce the seismic effects on the structure. In high-strength concrete, the effect of using high-strength cement will be greater in reducing cement consumption.
Keywords: *Earthquake, Structural strengthening, Building strength, Iran.*

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I. INTRODUCTION

Since Iran is one of the earthquake-prone regions in the world and has experienced very painful experiences in this regard, paying attention to earthquakes should be one of the main goals of experts in the field of construction (Kamranzad et al., 2020). The occurrence of an earthquake every few days with a magnitude of 4 on the Richter scale indicates the existence of a permanent danger, because every now and then a destructive earthquake with large human and financial losses has occurred (Motamed et al., 2019). The Bam earthquake is considered a turning point in terms of paying attention to basic and fundamental issues in crisis management and consequently increasing the stability of buildings and facilities against the risk of earthquakes (Hosseinnejad et al., 2022). Therefore, it is very necessary to pay attention to the retrofitting of buildings, important facilities, and vital arteries so that through retrofitting buildings, while saving human lives, increasing the stability of important structures against earthquakes, preserving national capital and improving the country's capacity helped to manage the crisis caused by the earthquake (Yoosefi Lebni et al., 2020).

However, unfortunately, many existing buildings and even new ones under construction do not have enough resistance against the lateral forces of the earthquake due to design and implementation weaknesses (Kurama et al., 2018), which will aggravate the damage caused by subsequent earthquakes (Yurdakul et al., 2021). So far, the effect of aftershocks has not been paid much attention in the science of earthquake engineering (Lagos et al., 2021). Structural seismic studies and analysis and probabilistic analysis of earthquake risk are focused on major earthquakes (Vandanapu et al., 2018). While the occurrence of strong aftershocks has shown that they can cause more damage or sometimes the collapse and destruction of structures that were not damaged by the main earthquake (Bojórquez et al., 2021). Therefore, the importance of calculating the probability of increasing vulnerability in important structures, including service structures after the main earthquake, such as hospitals and firefighting centers and crisis management, determines the importance of investigating the linear probabilistic analysis of aftershocks (Karadag et al., 2024; Takagi et al., 2019). In Iran, which is a country prone to earthquakes, the importance of studying the behavior of aftershocks is more evident (Nissen et al., 2019).

The present study was conducted to evaluate the seismic vulnerability of the joints of concrete structures with concrete wing walls in aftershocks. Housing buildings in Mehr suburb of Mashhad, which have concrete structures, are evaluated for their vulnerability to aftershocks. Phase 7 Mehr Mashhad housing buildings will be examined in 7, 10, and 13-story concrete structures.

II. MATERIALS AND METHODS

2.1. ETABS SOFTWARE

ETABS program takes into account all the seismic criteria of building design in the design of steel and concrete frames (Kumar et al., 2017). In this program, concrete frames can be designed based on normal, medium and special ductility criteria (Saikumar et al., 2022). The most important analytical capabilities of the program are recognition of building elements and floors, automatic calculation of mass and center of mass, transfer of gravity loads from floors to beams, generation and distribution of lateral loads between floor levels and modeling of shell elements and ramps (Mohan et al., 2017).

Also, in steel buildings, the special criteria of normal and special bending frames and convergent and divergent bracing systems can be included in the design. In addition to the above analysis and design capabilities, the ETABS program has full two-way communication with other software (Ahmad et al., 2020). The ETABS program automatically creates the SAFE input file. Also, ETABS program can create SAP2000 input file (Rathod et al., 2017).

2.2. BASICS OF THE PLAN

In the current research, a structure will be modeled which is considered to have 7, 10, and 13 floors and will be affected by the earthquake record near the Tabas fault, Iran. The wall is installed in the openings of the structure at a height of 3 meters and after being placed in the earthquake field, dynamic analysis and time history will be applied to them.

In the following and in the analysis process, the obtained results will be obtained in the form of capacity curve of the buildings as well as the relative lateral location change of the structure and the results will be compared with each other. Also, parameters such as axial force of columns, coefficient, shear, base of shear, classes of plastic joint formation pattern, plastic joint era, determination of damage index of shape and mass of mode, periodic time structure, elastic, inelastic periodic time and progressive dynamic analysis are considered in modeling.

In the modeling of this research, which is done with ETABS software version 9.7.4, 6 wall models will be modeled, which are simple wall, wall with wing length of 0.5 meters, wall with wing length of 1 meter and wall with wing length of 1.5 meters and a height of 3 meters will be modeled and the results of seismic analysis will be compared. The models built in the 5-6 meter openings will be subjected to near-field earthquakes, and these samples will be selected and applied from the acceleration maps of the meter. The field effect of the earthquake on the type of structure and cross-sectional characteristics of the shear wall will be one of the main objectives of the research. The required outputs of the analysis include the capacity curve of the structure and the drift and forces of the columns, the shear coefficient of the base and the shear of the floors, as well as the pattern of the formation of the plastic joints of the period and their progressive dynamic analysis.

II. RESULT AND DISCUSSION

Table 1 shows the minimum amount of extended live load based on the type of use of those floors based on the type of use. The minimum live load of the roof is determined by the maximum snow load and its type of use. In this project, the amount of live load equal to 200 kg/m2 on the concrete slab is considered.

Table 1: Load on concrete roof slab

Load name	Weight per volume unit in kilograms per square meter	Thickness (cm)	Weight per unit area in kilograms per square meter
Ceramic	2100	0.5	105
Cement sand mortar	2100	2.5	52.5
Pumice with brick chips	1500	3	45
Concrete slab	2500	15	375
Plaster plastered false ceiling	-	-	50
Overhead equivalent to partitioning	-	-	100

Total	633

Winged walls with wing lengths of 0, 5, 1, 1.5 and 2 meters were modeled and designed in a simple way. The sections assigned to the structures with the least amount of dispersion were selected and designed. The sections designed with ETABS are described in Table 2.

Table 2: Sections assigned to members

Floor class	Cross section of the beam	Column section
7 floors		
1-3	B 25X15	C 35X35
4-7	B 20X20	C 30X30
10 floors		
1-3	B 30X15	C 35X35
4-7	B 25X15	C 35X35
8-10	B 20X20	C 30X30
13 floors		
1-3	B 30X20	C 40X40
4-7	B 30X15	C 40X40
8-10	B 25X15	C 35X35
11-13	B 20X20	C 30X30

Table 3 shows the maximum displacement and drift of structures and Table 4 shows the energy and maximum shear force of the Tabas accelerometer.

Table 3: The maximum change of places and drift of structures floors

The length of the wing of the wall		The maximum displacement of the mass of the structure in the direction of 10^{-2} X	The maximum displacement of the mass of the structure in the direction of 10^{-2} Y	Drift in 10^{-3} X direction	Drift in 10^{-4} Y direction
7th floor	0	9.95	1.76	7.3	11.1
	0.5	7.94	1.48	5.47	9.25
	1	6.28	1.31	3.91	8.15
	1.5	4.97	1.2	2.94	7.42
	2	3.84	1.11	2.28	9.96
10th floor	0	17.7	4.11	9.71	18.1
	0.5	14.1	3.66	7.06	16.1
	1	11.5	3.38	5.2	14.8
	1.5	9.52	3.19	4	13.9
	2	7.72	3.03	3.21	13.4
13th floor	0	34.8	7.47	15.5	24.9
	0.5	17.3	6.5	6.77	21.9
	1	14.5	5.97	4.9	20.1
	1.5	13.1	5.7	4.44	19.2

	2	10.05	5.33	3.50	18.2

Table 4: Kinetic energy and maximum shear force in Tabas accelerometer

The length of the wing of the wall		Energy 10^{+2}	Maximum shear force 4^{+10}
7 floors	0	2.194	7.309
	0.5	2.462	8.567
	1	1.64	6.025
	1.5	1.505	7.474
	2	2.529	14.2
10 floors	0	1.707	10.75
	0.5	1.804	11.52
	1	2.128	11.01
	1.5	2.199	8.072
	2	1.954	12.42
13 floors	0	1.904	8.975
	0.5	1.979	6.219
	1	1.377	5.323
	1.5	1.860	11.9
	2	1.100	9.146

Based on the contents of Table 4, it is clear that in all structures, the maximum displacement of the mass of the structure in the X direction decreases with the increase in the length of the wing of the structure, and it can be concluded that the increase of the wing reduces the horizontal displacement of the wall (Gkournelos et al., 2021). Also, with the increase in the length of the wing of the wall, the drift decreases, and also the maximum amount of drift or the increase in the length of the wing is directed towards the higher floors and the upper middle of the structure. Based on the results, it is clear that in the structure of 7, 10 and 13 floors, respectively, the wall with 1.5 meter and 1 meter wing, the wall with 1.5 meter wing and the wall with 2 meter wing had the best behavior.

IV. CONCLUSION

Based on the modeling and the obtained results, it can be seen that the structures with 1 and 1.5 meter wings have shown better behavior. Walls with a wall length of 1 and 1.5 meters have good behavior against seismic forces, and walls with a wall length of 1.5 meters have shown almost the best output against earthquakes, and walls without wings or with wings of 0.5 meters They have not shown good behavior. The following technical results are presented case by case:

- In the parallel direction of the wings, with the increase of the maximum layers, the shear force distribution interval decreases.
- With the increase of the maximum floors, the shear force distribution interval in the walls increases.
- Increasing the floors increases the maximum range of shear force perpendicular to the wings.
- In all structures, the maximum displacement of the mass of the structure in the X direction decreases with the increase in the length of the wing of the structure.

According to the damages and losses caused by earthquakes in earthquake-prone countries and according to the results of the tests and the investigation and study of buildings damaged by intermittent earthquake loads, it can be seen that joints, the weakest and most vulnerable part of concrete structures against loads are caused by earthquakes. Therefore, it is necessary to conduct more investigations on the connections of concrete structures. This issue becomes more important in earthquake-prone countries, including Iran.

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