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Effects of adding illegal storeys to structural systems

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Abstract. Earthquakes in Turkey are frequently occurring disasters, causing much loss of life and property. It is tragic indeed that earthquakes should share the agenda with amnesty laws for illegal buildings. Illegal buildings are those constructed without authorization, legal bureaucratic sanction and, in most cases, without normal engineering control and checks. Buildings may become illegal for a variety of reasons. The very prospect of a waiver bill for illegal buildings spurs further illegal construction. The status of illegal buildings may legally change in time. What is an illegal building today may well be legal tomorrow under these circumstances.

The present study deals with two different kinds of building: one is the framed building and the other has shear-wall frame. The capacity ratios, storey drifts and natural periods for the legally approved buildings and the effects of illegal or legal additional floors on these values are compared. It is determined that these buildings with illegal storeys should be strengthened and retrofitted by providing cast in-situ reinforced concrete shear walls.

Keywords. Amnesty laws for illegal buildings; seismic retrofitting; storey drifts; column capacity ratios.

1. Introduction

A series of amnesty laws for illegal buildings (and all unauthorized construction) is always on the agenda of Turkey. Illegal buildings are various and numerous and their legal status may change with time, with the result that an illegal building today may well be legalised tomorrow. Each new waiver bill makes some more illegal buildings legal. Time is therefore of the essence. The changed situation here does not affect the structural nature of the building, but only its legal conformity and acceptance. Therefore "illegal building" as a term should be discussed. An illegal building may be built without acquiring the land rights in a suburb or it may be a luxurious building in an elegant district (Kahraman & Misir 2004).

For instance, a building may even be illegal from the viewpoint of its location. This also may vary: the building might be built on someone else's land, on land belonging to the State,

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in a river valley or in an area affected by landslides. Buildings that have been constructed in river valleys or landslide areas, in particular, are not safe from natural disasters. Problems that are probable when illegal buildings are legalized via a *building waiver bill*, comprise an interdisciplinary subject and call for further study.

Apart for the above mentioned buildings, there are buildings which have no project basis, i.e. are not based on formal design calculations and drawings, or buildings which have not been constructed in accordance with their project calculations, if any, and those which contain more floors than are shown in the original project etc. It is possible to enlarge the scope and content of the term *illegal building*.

It is disappointing and surprising that despite the fact that experts (engineers, architects, earth scientists, city planners, social scientists etc.) outlined the measures that needed to be taken after the disastrous major earthquake in Turkey in August 1999, which caused the death of tens of thousands of people, in addition to huge economical losses and considerable ill effects on society, few of them were seriously implemented by the authorities. This is not something which normally happens or should happen in a country with frequent earthquakes.

2. Methodology

This study deals only with one facet of a vast topic. Here, for typical structures, the capacity ratios, storey drifts and natural periods of a legal building are calculated and the effects of illegal and legal additional floors on these values are examined and compared (TS498 1997; TS500 2000; Computers & Structures 2000).

It is assumed that the buildings were built according to the original proposal. However, it is obvious that this is not usually the case. Most optimistically, even if it is presumed that a building is built according to the original project and code, it is known that the reinforcing steel used may often be of substandard quality.

Even if the material conforms to standards, and construction is well monitored, buildings may not be able to support additional floors. The most innocent addition to a building, even a terrace, affects the dynamic behaviour of the building and changes its torsional irregularities. In locations where settlement tendency exists, where the soil is cohesive and groundwater level is high, additional floors might also cause geotechnical problems.

In this paper, two types of building: one with frame (F) and the other with shear-wall frame (SWF) are chosen (figures 1a and b). It is assumed that these buildings are situated in the most severe earthquake zone, the ground is soft and has deep alluvial layers with a high water table. The effective ground acceleration coefficient, A_0, is assumed to be 0.4. The same grid plan is used in all of the floors, and the columns are assigned to the axis passing through their centroids (Turkish Earthquake Specification 1998).

The concrete used is C20 whose cylindrical compressive strength is 20 MPa, and the building steel used is S420 whose characteristic yield strength is 420 MPa. On each of the two building models, the columns are taken as 45 × 45 cm in dimension and reinforced with 16 longitudinal bars which are 16 mm in diameter along the axis D. Other columns are of 40 × 40 cm dimension and reinforced with 12 longitudinal bars of the same diameter. The beams are 25 × 50 cm in dimension, floor slabs are 14 cm in thickness, and each storey is 3·0 m in height. The shear-walls are 25 × 200 cm in dimension and reinforced with 44 longitudinal bars which are 16 mm in diameter. After the calculations have been performed for these 4-storey buildings (4-Sb), the analyses below are conducted for three new additional floors:

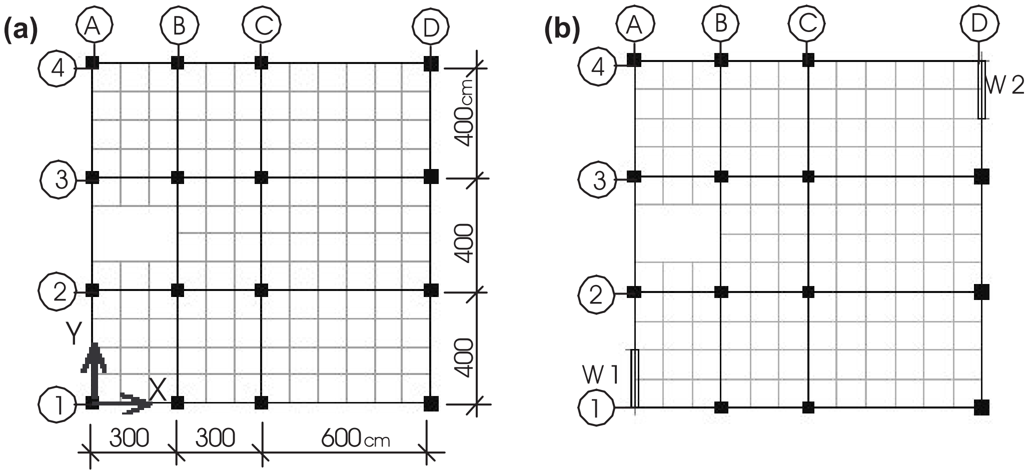


Figure 1. The plan of an F building (**a**) and of an SWF building (**b**).

- Addition of a terrace dwelling covering part of the plan (t-f) (figure 2)
- Additional complete storey (5-sb)
- Two additional complete storeys (6-sb)

To find the most critical loading, the following types of load combinations are taken into consideration:

- $1{\cdot}4\,\mathrm{D} + 1{\cdot}6\,\mathrm{L}$,
- $1{\cdot}0\,\mathrm{D} + 1{\cdot}0\,\mathrm{L} + 1{\cdot}0\,\mathrm{E}_x$ (±%5 additional eccentricities),
- $1{\cdot}0\,\mathrm{D} + 1{\cdot}0\,\mathrm{L} + 1{\cdot}0\,\mathrm{E}_y$ (±%5 additional eccentricities),

where D and L stand for Dead and Live Load respectively, and E_x and E_y symbolize the effects obtained from response spectrum analysis in both directions. In seismic analysis, the

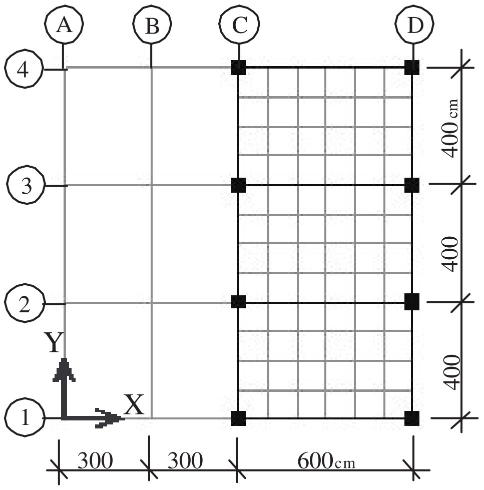
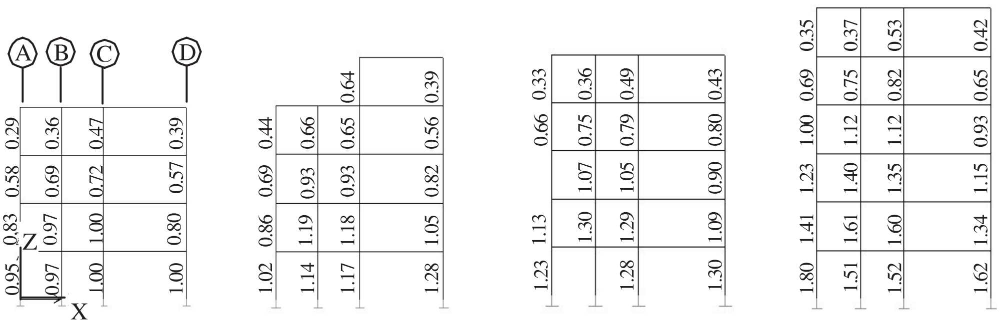


Figure 2. Terrace floor of F and SWF buildings.



(a) (b) (c) (d)

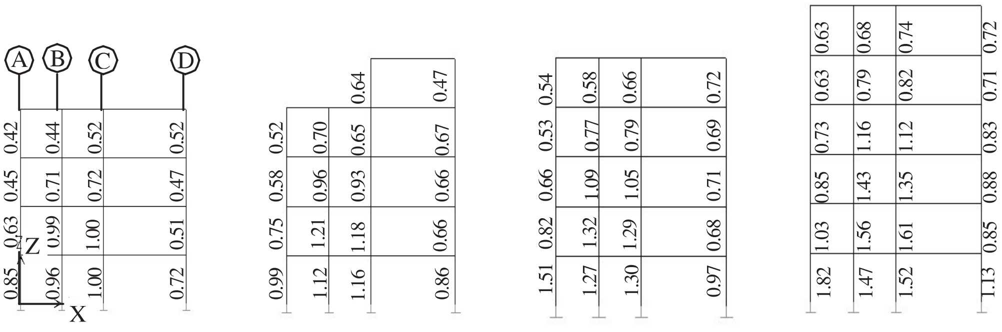
Figure 3. The column capacity ratios for axis 2-2 of F buildings: **(a)** 4-storey, **(b)** 4-storey with terrace floor, **(c)** 5-storey, **(d)** 6-storey building.

mode superposition method is used and ± 5 % additional eccentricities are also taken into account in the calculations carried out by the building analysis and design software ETABS v7·19 (Chopra 1995; Wilson 1998; ETABS 2000, 2001).

3. Results

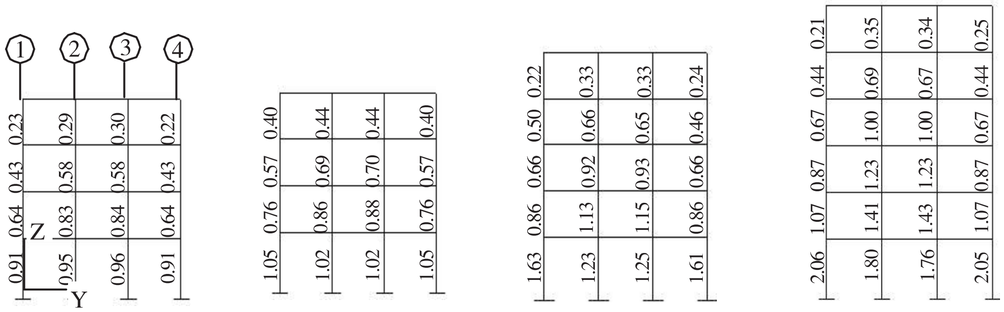
In this study, comparisons between the original and the illegal storey-added buildings are made by the column capacity ratios which give indications of the stress condition of the column with respect to the capacity of the column. The column capacity ratios of two chosen axes perpendicular to each other, i.e. axes 2-2 and A-A, are presented in figures 3 through 6.

The first five natural periods of F and SWF buildings are given in table 1, and the storey drift ratios of both building types for the direction Y in which the rigidities of the buildings differ more obviously from each other are presented in table 2. It is seen that the drift ratio values are nearly same in cases of a terrace and a complete storey addition. As can be



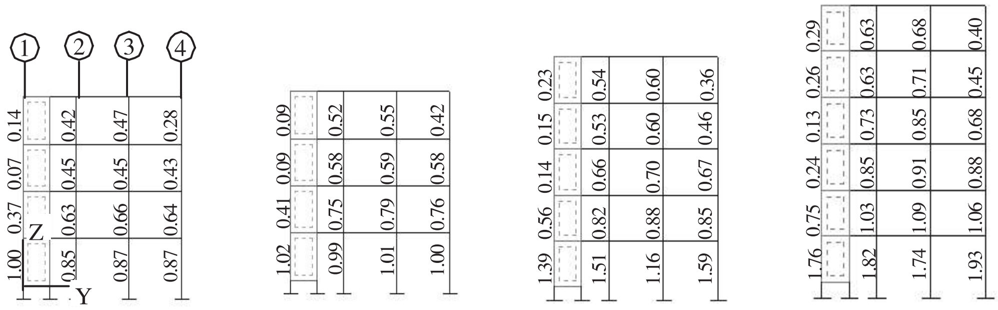
(a) (b) (c) (d)

Figure 4. The column capacity ratios for axis 2-2 of SWF buildings: **(a)** 4-storey, **(b)** 4-storey with terrace floor, **(c)** 5-storey, **(d)** 6-storey building.



(a) (b) (c) (d)

Figure 5. The column capacity ratios for axis A-A of F buildings: **(a)** 4-storey, **(b)** 4-storey with terrace floor, **(c)** 5-storey, **(d)** 6-storey building.



(a) (b) (c) (d)

Figure 6. The column and shear-wall capacity ratios for axis A-A of SWF buildings: **(a)** 4-storey, **(b)** 4-storey with terrace floor, **(c)** 5-storey, **(d)** 6-storey building.

Table 1. Natural periods (s) of F and SWF buildings.

Modes	Models							
	4-Storey building		Building with terrace floor		5-Storey building		6-Storey building	
	F	SWF	F	SWF	F	SWF	F	SWF
1 (u_x)	0·50	0·50	0·59	0·59	0·63	0·65	0·77	0·78
2 (u_y)	0·49	0·38	0·59	0·48	0·63	0·50	0·76	0·63
3 (rot_z)	0·37	0·29	0·43	0·35	0·47	0·38	0·57	0·48
4 (u_x)	0·16	0·16	0·20	0·20	0·21	0·21	0·25	0·25
5 (u_y)	0·16	0·10	0·19	0·14	0·20	0·13	0·25	0·17

Table 2. Storey drift ratios ($\Delta_{\max}/h$) of F and SWF buildings in direction Y for elements $D-4$ (%).

	$\Delta_{\max}/h$	
Models	F	SWF
4-Storey building	2·6	1·5
Building with terrace floor	3·5	2·3
5-Storey building	3·6	2·3
6-Storey building	4·5	3·1

seen in figure 1a and table 1, the rigidities and the consequently natural periods of F building are nearly the same in both directions. For an SWF building, due to two shear-walls used, the rigidity in the Y direction is considerably bigger than the other one, and therefore the natural periods for this case are smaller than those obtained for frame building, as expected.

In figures 3 and 4, it may be observed that the most critical column in axis 2-2 for internal forces is on the ground floor and situated at location A-2. The internal forces and the capacity ratios obtained for this column for framed and shear-wall frame buildings are presented in tables 3 and 4 respectively. The tables include two different values for each internal force, found under the loading corresponding to the maximum column capacity ratios (I) and the maximum ones (II). The maximum internal forces given in these tables may have been obtained for different loadings.

The internal forces and the capacity ratios obtained for column A-1 of the F buildings and shear-wall W1 of the SWF buildings are presented in tables 5 and 6 respectively, so that the behaviour differences between a column and the shear wall used instead may be seen.

Tables 7 and 8 give the relative changes in capacity ratios of all columns and shear walls in the system when new floors are added, compared to the capacity ratios of 4-storey F and SWF buildings respectively. The decrease in the capacity ratios of the shear-walls in storey 4 is due to the difference in the F and SWF behaviour.

Table 3. Internal forces and capacity ratios for column A-2 at base floor of F building.

	Axial force [kN]		Bending moment [kNm]				
			M_x		M_y		Column capacity ratio
Models	I	II	I	II	I	II	
4-Storey building	408	720	169	169	3·0	158	0·95
Building with terrace floor	857	857	19·0	159	183	216	1·02
5-Storey building	504	1023	220	220	6·3	200	1·23
6-Storey building	1283	1357	32·4	268	230	241	1·80

Table 4. Internal forces and capacity ratios for column A-2 at base floor of SWF buildings.

	Axial force [kN]		Bending moment [kNm]				
			M_x		M_y		Column capacity ratio
Models	I	II	I	II	I	II	
4-Storey building	574	574	5·7	49	155	155	0·85
Building with terrace floor	688	688	7·8	49	179	179	0·99
5-Storey building	804	827	19·5	67	198	203	1·51
6-Storey building	1073	1104	22·4	83	226	234	1·82

Table 5. Internal forces and capacity ratios for column A-1 at base floor of F buildings.

	Axial force [kN]		Shear force [kN]		Bending moment [kNm]				
					M_x		M_y		Column capacity ratio
Models	I	II	I	II	I	II	I	II	
4-Storey building	565	565	89	89	11	153	165	165	0·91
Building with terrace floor	679	679	103	103	13	153	192	192	1·05
5-Storey building	778	826	107	114	29	197	204	213	1·63
6-Storey building	1056	1121	129	136	34	238	247	257	2·06

Table 6. Internal forces and capacity ratios for shear-wall W1 at base floor of SWF buildings.

	Axial force [kN]		Shear force [kN]		Bending moment [kNm]				
					M_x		M_y		Shear-wall column capacity ratio
Models	I	II	I	II	I	II	I	II	
4-Storey building	407	632	520	522	2362	2362	5	183	1·00
Building with terrace floor	455	735	494	495	2373	2373	16	213	1·02
5-Storey building	560	935	676	681	3247	3253	12	242	1·39
6-Storey building	746	1290	820	822	4088	4088	17	280	1·76

Table 7. The relative changes in column capacity ratios of 4-storey (with terrace floor) (t-f), 5-storey (5-sb), and 6-storey (6-sb) F buildings [%].

Name	Storey 1			Storey 2			Storey 3			Storey 4		
	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb
A1	15	79	126	19	34	67	33	53	102	74	117	191
A2	7	29	89	4	36	70	19	59	112	52	128	245
A3	6	30	83	5	37	70	21	60	112	47	117	233
A4	15	77	125	19	34	67	33	53	102	82	109	205
B1	17	30	60	21	35	67	34	55	103	80	113	210
B2	18	27	56	23	34	66	35	55	103	83	108	211
B3	18	27	56	23	34	66	35	55	103	83	108	211
B4	17	30	59	23	36	69	34	55	104	80	113	210
C1	17	30	72	17	30	76	28	48	105	43	73	143
C2	17	28	52	18	29	60	29	46	88	38	68	138
C3	17	28	52	18	29	60	29	46	88	38	68	138
C4	17	30	72	16	29	76	28	47	107	35	73	143
D1	31	30	98	26	32	62	37	49	89	26	81	93
D2	28	30	62	31	36	68	44	58	102	44	105	138
D3	26	31	60	29	34	65	44	56	100	41	105	138
D4	26	30	107	26	38	74	35	32	74	43	75	71

When the values in the tables are examined, it is seen that the relative increase in the column capacity ratios are larger in upper storeys. However, any chosen column dimension is the same in all storeys in both the present study and most of the buildings encountered in

Table 8. The relative changes in column and shear-wall capacity ratios of 4-storey with terrace floor (t-f), 5-storey (5-sb), and 6-storey (6-sb) SWF buildings [%].

Name	Storey 1			Storey 2			Storey 3			Storey 4		
	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb
W1	2	39	76	11	51	103	29	100	243	−36	0	−7
A2	16	78	114	19	30	63	29	47	89	24	26	74
A3	16	33	100	20	33	65	31	56	102	17	28	81
A4	15	83	122	19	33	66	35	56	105	50	64	143
B1	18	34	59	22	35	69	34	57	105	72	98	193
B2	17	32	53	22	33	58	35	54	101	59	75	164
B3	18	33	53	21	32	63	36	56	104	57	73	159
B4	17	35	57	22	34	71	34	55	108	81	100	195
C1	16	31	64	17	28	73	30	48	88	34	64	134
C2	16	30	52	18	29	61	29	46	88	25	52	115
C3	16	32	52	19	29	63	29	45	86	35	61	129
C4	15	33	70	16	27	82	29	49	114	36	64	128
D1	16	32	55	26	31	67	53	47	81	17	26	46
D2	19	35	57	29	33	67	40	51	87	29	33	60
D3	20	38	59	29	34	68	36	52	88	11	0	20
W2	35	38	73	49	51	100	125	113	238	−29	−21	0

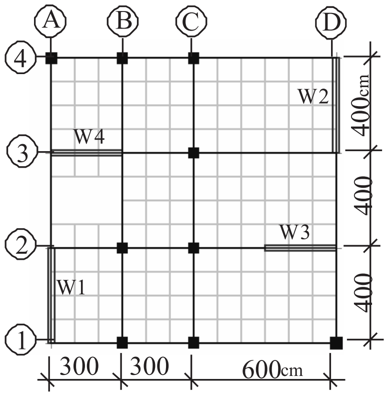


Figure 7. Plan of a retrofitted building.

practice, especially those constructed with reinforced concrete. Hence, on account of minimum section and reinforcement requirements and construction practicability, the capacity ratios of first storey columns generally exceed the critical level when illegal storeys are added. If the columns and shear-walls are designed in limit dimensions which make capacity ratios approach 1, the most critical columns will be ones in the upper storeys.

4. Retrofitting of existing illegal storey-added buildings

It is obvious that, when the values in the related tables are perused, in the case of addition of new floors to these buildings, the columns considered do not provide sufficient resistance. Hence, if new floors are added, in order to cope with the new internal forces which occur in the columns, column capacities should be considerably more than in the previous case. Consequently, buildings have to be strengthened to resist seismic forces (Utku & Wasti 1997; Fardis 2003). As a method of strengthening to restore structures to at least the life-safety level, the provision of cast in-situ reinforced concrete shear walls throughout the height of the buildings in both directions is chosen. As can be seen in figure 7, a shear wall 25 × 400 cm in dimension, reinforced with 84 longitudinal bars which are 16 mm in diameter on each of the axes A and D in direction Y, and a shear wall 25 × 300 cm in dimension reinforced with 62 longitudinal bars with the same diameter on each of the axes 2 and 3 in direction X are added to both types of buildings.

When the original buildings are analysed for only vertical loads, as shown in table 9, it is observed that the column capacity ratios even on the ground floor do not exceed the critical

Table 9. Capacity ratios of ground storey columns of two types of 6-storey-buildings before retrofitting for vertical load combination (1·4 D + 1·6 L).

	Framed building				Shear-wall frame building			
Axes	A	B	C	D	A	B	C	D
1	0·29	0·39	0·55	0·35	0·11	0·37	0·55	0·35
2	0·43	0·57	0·79	0·51	0·31	0·55	0·80	0·51
3	0·43	0·57	0·79	0·51	0·43	0·57	0·79	0·41
4	0·29	0·39	0·55	0·35	0·29	0·40	0·56	0·15

Table 10. Natural periods (T) of retrofitted buildings [s] and their relative decrease with respect to unretrofitted buildings [%].

	Models								
	Building with terrace floor			5-Storey building			6-Storey building		
Modes	T	F	SWF	T	F	SWF	T	F	SWF
1 (u_x)	0·36	39	39	0·37	41	43	0·47	39	40
2 (u_y)	0·29	51	40	0·31	51	38	0·41	46	35
3 (rot$_z$)	0·21	51	40	0·24	49	37	0·31	46	35
4 (u_x)	0·13	35	35	0·09	57	57	0·12	52	52
5 (u_y)	0·12	37	14	0·07	65	46	0·09	64	47

value, i.e. 1. For this reason, in the analysis of retrofitting, it was assumed that the existing buildings have not yet experienced any noticeable earthquake and therefore are undamaged. Accordingly, the mechanical characteristics of materials have been assumed to have the same values as used in the previous analyses without any reduction, especially for the concrete. Hence, to compare results, the new added shear walls have also been made using the same materials of comparable quality.

The first five natural periods and the storey drift ratios of retrofitted buildings together with their relative changes with respect to original buildings with illegal storeys are given in tables 10 and 11 respectively.

Table 12 gives the column and shear-wall capacity ratios of retrofitted buildings in case of new floor additions.

5. Conclusions

In the present study, effects of additional floors on buildings are investigated and the obtained column capacity ratios, natural periods and maximum storey drift ratios are compared with those of an existing 4-storey building. The comparisons indicate that the elements of 4-storey framed and shear-wall frame buildings cannot support additional floors or terraces. As the weight of the additional floor increases, the internal forces and consequently the required column capacity also increase. If the original 4-storey buildings have been designed properly

Table 11. Storey drift ratios ($\Delta_{\max}/h$) of retrofitted buildings in direction Y and their relative decrease with respect to unretrofitted buildings at $X = 12$ m and $Y = 12$ m.

		Relative changes [%]	
Models	$\Delta_{\max}/h$ [%]	F	SWF
Building with terrace floor	0·92	74	60
5-Storey building	0·98	73	57
6-Storey building	1·37	70	56

Table 12. Column and shear-wall capacity ratios of retrofitted buildings.

	Storey 1			Storey 2			Storey 3			Storey 4		
Name	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb	t-f	5-sb	6-sb
W1	0·49	0·70	0·90	0·28	0·43	0·58	0·14	0·23	0·34	0·05	0·08	0·16
W2	0·73	0·77	1·00	0·46	0·49	0·67	0·25	0·27	0·40	0·09	0·11	0·20
W3	0·85	0·76	0·97	0·45	0·41	0·55	0·20	0·19	0·28	0·06	0·08	0·14
W4	0·87	0·79	1·00	0·51	0·42	0·56	0·26	0·20	0·29	0·10	0·08	0·14
A4	0·26	0·32	0·27	0·26	0·32	0·29	0·24	0·28	0·32	0·27	0·23	0·28
B1	0·26	0·30	0·36	0·36	0·40	0·43	0·43	0·46	0·45	0·53	0·49	0·43
B2	0·38	0·44	0·50	0·36	0·41	0·48	0·37	0·41	0·46	0·44	0·39	0·43
B4	0·28	0·31	0·38	0·37	0·38	0·48	0·40	0·40	0·51	0·50	0·38	0·49
C1	0·45	0·43	0·51	0·48	0·47	0·43	0·48	0·48	0·40	0·46	0·47	0·35
C2	0·65	0·46	0·54	0·58	0·50	0·56	0·52	0·51	0·68	0·45	0·55	0·75
C3	0·64	0·61	0·70	0·66	0·67	0·63	0·62	0·64	0·60	0·57	0·61	0·51
C4	0·43	0·45	0·54	0·44	0·49	0·47	0·42	0·47	0·48	0·39	0·45	0·44
D1	0·31	0·29	0·37	0·36	0·31	0·38	0·32	0·28	0·35	0·30	0·29	0·31

by considering seismic forces, as may be seen in table 9, these buildings can bear vertical loads in case of new floor additions. However, analysis results show that these structures may be expected to collapse even in a moderate earthquake. In an atmosphere where engineering services are not adequate, where there are distortions and arbitrariness in the implementation of existing laws and regulations, and where construction of additional storeys is retrospectively legalized by amnesty laws, the main problem is to be able to bring in urgent, realistic and practicable solutions to prevent the collapse of these types of buildings during earthquakes that might occur. The economic conditions of the inhabitants of these buildings must also be considered to suggest proper solutions and not financially overburden them.

In this paper, the provision of cast in-situ reinforced concrete shear walls throughout the height of the buildings in both directions, which is a widely used strengthening method, is chosen as an example of application. The added shear walls are designed to have approximately 1% of the base area of the structure in each direction, and it is observed that the natural periods and relative drift ratios decrease significantly while column and shear wall capacity ratios do not exceed critical values.

Medium strength earthquakes, which occur frequently in Turkey, should be considered seriously by engineers. The worst aspect of the matter is to get innured to the damage caused by such events, consider these disasters as normal and remain just onlookers. Earthquakes undoubtedly cause major problems. However, even if it is not possible to completely recover from or avoid these problems, it is possible to mitigate their effects. One of the significant measures to be taken is to stop the waiver bill to legalise such buildings, and be aware of the dangers they cause. It is necessary to develop public awareness about the subject, to provide for the active contributions of civil engineers to this process and to develop realistic policies.

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