Seismic Evaluation of Concrete Wall Buildings

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SUMMARY:
Concrete shear walls are commonly used as a building's seismic force resisting system. Because of changing strength demand and ductility requirements in the building codes due to advances in our understanding of seismic behaviour, existing buildings may not have adequate seismic resistance. A number of methodologies have been developed for rapid seismic assessment of existing buildings. In the United States, the most commonly used standard for the seismic assessment of existing buildings is the three tier evaluation methodologies in ASCE 31-03 Seismic Evaluation of Existing Buildings. The first tier of ASCE 31-03 is a screening phase that includes an approximate force-based procedure for assessing whether the building's lateral force resisting system has sufficient strength. This procedure uses a pseudo lateral force calculated for the building based on the seismic hazards present in the area and an approximate procedure for calculating the lateral force capacity of the seismic force resisting system. The results of the ASCE 31-03 screening procedure for concrete shear wall buildings is compared to the performance predicted by the priority index procedure of Hassan and Sozen to assess the usefulness of the procedure to concrete shear wall buildings in the United States.

Keywords: Concrete, Shear Wall, Screening

1. INTRODUCTION

Throughout the world there is a large inventory of existing buildings that were designed and constructed prior to the implementation of modern seismic design requirements. As part of a seismic risk evaluation, existing buildings are often assessed for their seismic vulnerability. Various techniques have been developed to evaluate the vulnerability of existing buildings, ranging from rapid screening procedures, such as *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (FEMA 154) [FEMA 1988], to complex analytical procedures, such as *Seismic Rehabilitation of Existing Buildings* (ASCE 41-06) [ASCE 2007]. Typically, engineers employ approximate procedures to evaluate seismic vulnerabilities of buildings that require a level of effort between the rapid screening and the complex analytical techniques. A common procedure used in the United States for evaluating the seismic vulnerability of existing buildings is *Seismic Evaluation of Existing Buildings* (ASCE 31-03) [ASCE 2003]. This procedure employs a three-tier process, ranging from a screening phase to a detailed analysis phase.

Buildings constructed with concrete shear walls as the lateral force resisting system are common in many areas of the world. The performance of concrete buildings in large earthquake has been studied in several countries to assess the adequacy of the design and construction of concrete buildings with various amounts of concrete shear walls. In Chile, for example, good performance of buildings in the Viña del Mar area was documented by Wood [1991] for buildings with typical ranges of cross sectional area of concrete shear walls to floor area used in Chile. Residential mid-rise and high rise buildings in the area were typically constructed with a ratio of concrete shear wall area to floor plan area between 2 percent and 4 percent. Riddell et al [1987] also presented data from Chile and compared the buildings in Viña Del Mar to indices that were developed in Japan for low rise school buildings.

In Turkey, following the 1992 Erzincan earthquake, a procedure was developed for evaluating concrete buildings concrete shear walls [Hassan 1997]. This procedure considers the seismic vulnerability of buildings by evaluating the ratio of the cross sectional area of shear walls to the total floor area, in addition to the cross sectional area of concrete columns and masonry shear walls. This methodology results in a priority index for the building in each direction. The priority index, which is also referred to as the Hassan Index, was determined for a number of buildings in Turkey and was compared to the actual performance of the buildings in the 1992 earthquake.

The scope of this study illustrate the similarities between the Hassan Index and the screening phase of the ASCE 31-03 Tier 1 procedure for concrete shear wall type buildings.

2. DESCRIPTION OF PROCEDURES

The basic methodologies for the ASCE 31-03 Tier 1 and the priority index are described below.

2.1. ASCE 31

The Tier 1 procedure in ASCE 31-03 is termed a screening phase. The intent is to categorize buildings by their building type and then to evaluate certain significant lateral load resistance characteristics of the specific building type by the use of a series of checklist statements. Applicable checklist statements vary depending on the building construction type and the seismic hazard associated with the site. The checklist statements are intended to be conservative measures of vulnerability so that buildings that pass the screening phase are very likely to perform adequately in a design earthquake. Buildings that have some deficiencies identified by the screening phase, the buildings can be further evaluated using procedures in Tier 2 or Tier 3, which are intended to provide a more sophisticated estimation of the seismic performance.

For concrete shear wall buildings, an approximate calculation of the shear stress in the shear walls is carried out as part of the Tier 1 procedure. The seismic hazard at the site is determined in terms of spectral acceleration, which is a function of the fundamental period of the building as represented by an elastic response spectrum. The spectral acceleration is calculated based on the acceleration values for the Maximum Considered Earthquake (MCE) for the site as determined by the U.S. Geological Survey, which typically represents an earthquake with an annual probability of exceedence of 2475 years. The spectral acceleration is increased to account for site specific soil effects and then multiplied by a factor of 2/3 to convert the MCE earthquake to a design level event.

The seismic hazard is multiplied by a coefficient and by the weight of the building to determine the seismic base shear demand, which is vertically distributed to each story of the building. The shear stress is computed by dividing the seismic shear demand at each level by the total cross sectional area of the shear walls at each story. The calculated shear stress is compared to an approximate capacity, calculated using $2\sqrt{f'c}$ (in English units) times a component modification factor m. The m factor is a conservative approximation of the ratio of ultimate strength to yield strength accounting for component ductility and overstrength. The expected performance of buildings that pass the ASCE 31-03 Tier 1 screening is categorized as Life Safety. Life Safety is considered to be a performance level associated with a margin of safety against collapse of in the range of 1.25 and 1.5.

2.2 Priority Index

Following the 13 March 1992 Erzincan Earthquake in Turkey, a screening method for concrete shear wall buildings was developed to assess the vulnerability of low-rise concrete buildings [Hassan 1997]. The proposed method considers the cross sectional area of the concrete walls, the concrete columns, and the unreinforced masonry infill walls and compares the wall and column areas to the total floor area of the building above the base. For the determination of the effectiveness of the building's seismic resistance, the area of concrete shear walls in each direction is added to 10 per cent of the area of unreinforced masonry walls in that direction and divided by the total floor area above the base to determine a Wall Index, WI, as shown in Eqn. 2.1. A Column Index, CI, is obtained by considering 50 per cent of the area of concrete columns as effective in a given direction and dividing the value by the total area of floors above, as shown in Eqn. 2.2. The priority index is the sum of the Column Index and the Wall Index.

$$WI = \frac{A_{cw} + \frac{A_{mw}}{10}}{A_{ft}} 100 \tag{2.1}$$

$$CI = \frac{\frac{A_{col}}{2}}{A_{ft}} 100 \tag{2.2}$$

Where:
A_{cw} is the cross section area of concrete walls in a given direction,
A_{mw} is the cross sectional area of unreinforced masonry walls in a given direction,
A_{col} is the cross sectional area of concrete columns, and
A_{ft} is the total floor area of the building above the base.

The performance of a number of buildings in the Erzincan Earthquake was compared to the calculated priority index. Increasing damage was observed for lower values of the priority index and two threshold values were proposed as indicators of relative risk. The upper value of 0.5 was proposed as an indication of moderate risk of severe damage and a value of 0.25 as an indication of relatively high risk of severe damage.

3. COMPARISON OF PROCEDURES

Although the methodologies of the ASCE Tier 1 screening phase and the priority index appear to be vastly different, there are some aspects of the two procedures that are similar enough to allow for a comparison using some simplifying assumptions. The priority index considers the contribution of concrete shear walls, masonry walls, and concrete columns. For the purpose of comparison, the contribution of the masonry walls is ignored since buildings are generally not designed to have masonry walls resisting seismic forces in combination with concrete walls in the United States. Furthermore, because of differences in strength and ductility of reinforced concrete and unreinforced masonry walls, the masonry walls are not likely to contribute to the lateral strength of the building when the reinforced concrete shear walls are pushed to their ultimate strength. Additionally, the ASCE 31-03 procedure considers only the shear contribution of the concrete shear walls and ignores any shear contribution of the concrete columns since the relative stiffness of the walls is usually much greater than that of the columns. Therefore, to be consistent with the ASCE 31-03 procedure, we also ignored the contribution of the columns in calculating the priority index for the building.

The fundamental premise of the ASCE 31-03 Tier 1 procedure to evaluate the adequacy of the shear walls is a comparison of a demand to a capacity. The demand is expressed as shown in Eqn. 3.1.

$$V = CS_a W \tag{3.1}$$

Where:
V is the seismic base shear force;
C is a coefficient intended to relate expected inelastic displacements to displacements determined from

elastic analysis;
S_a is the spectral response acceleration at the building's fundamental period; and
W is the effective seismic weight of the building.

The seismic weight of the building can be calculated as the sum of the weight of each floor level of the building as shown in Eqn. 3.2.

$$W = \sum^{n} A_f w_i \tag{3.2}$$

Where:
n is the number of floors above the base,
A_f is the area of a floor, and
w_i is the average unit weight of the floor.

If we assume that the unit weight of each floor is the same and combine Eqn. 3.1 and 3.2 we get Eqn. 3.3.

$$V = CS_a w \sum^{n} A_f \tag{3.3}$$

The ASCE 31-03 Tier 1 procedure uses the following equation (Eqn. 3.4) to calculate the average shear stress in the shear walls.

$$v^{avg} = \frac{1}{m} \frac{V}{\sum A_w} \tag{3.4}$$

Where:
v^{avg} is the average shear stress in the shear walls at a given level;
m is component modification factor that accounts for ductility and overstrength of the element;
A_w is the cross sectional area of a shear wall at a given level.

By combining Eqn. 3.3 and Eqn. 3.4, we get the following expression in Eqn. 3.5 for average shear stress in the shear walls.

$$v^{avg} = \frac{1}{m} \frac{CS_a w \sum^{n} A_f}{\sum A_w} \tag{3.5}$$

The ASCE 31-03 Tier 1 procedures prescribes the allowable average shear stress, using English units, to be the lesser of 100 psi or $2\sqrt{f'_c}$. The average shear stress is compared to the allowable shear stress by substituting Eqn. 3.5 and the allowable shear stress based on the concrete strength value in Eqn. 3.6.

$$\frac{1}{m} \frac{CS_a w \sum^{n} A_f}{\sum A_w} < 2\sqrt{f'_c} \tag{3.6}$$

By rearranging the terms of Eqn. 3.6 to put it in the form similar to that of the Wall Index (Eqn. 2.1), we can express the acceptability of the building as shown in Eqn. 3.7.

$$\frac{\sum A_w}{\sum^n A_f} > \frac{CS_a w}{m2\sqrt{f_c'}} \tag{3.7}$$

If both sides of the expression are multiplied by 100, the left side of the expression becomes the Wall Index used by Hassan and Sozen. The right side of the expression therefore becomes an acceptable wall area ratio, WR, which can be defined as shown in Eqn. 3.8.

$$WR = \frac{100CS_a w}{8\sqrt{f_c}} \tag{3.8}$$

Eqn. 3.7 provides a simplified expression for evaluating buildings categorized as concrete shear wall buildings using several variables. The above expression can be compared to the ratio of the sum of the area of the shear walls to the sum of the floor areas. This procedure can provide a simpler form of a screening evaluation using a format consistent with the priority index screening procedure. In the expression for acceptable wall ratio, the value of C is prescribed in ASCE 31-03 to be 1.0 for concrete shear wall buildings that are at least four stories in height and 1.1 for buildings three stories or less in height. ASCE 31-03 also provides a value for m of 4 for concrete shear walls being evaluated for Life Safety performance. Therefore, the wall ratio is dependent on three variables: the design spectral acceleration at the site, the average unit weight of the floors, and the strength of the concrete in the shear walls.

4. CASE STUDIES

Several buildings which primarily rely on concrete shear walls as the lateral force resisting system were evaluated using the ASCE 31-03 Tier 1 procedure and the priority index procedure. The configuration of each of the buildings and the general seismic hazard at the site are described below. Table 4.1 summarizes the results of the evaluations of the buildings using both the priority index and the ASCE 31-03 Tier 1 methodology. For each building, except building 5, the results are reported for the first story above grade. For building 5, the results are reported for the second story above grade. Values for each orthogonal direction are listed on separate lines in the table. For the Tier 1 methodology, the seismic hazard was based on the short period spectral acceleration for two-thirds of the Maximum Considered Earthquake (MCE), as prescribed by ASCE 31-03, using values obtained from the U.S. Geological Survey.

Table 4.1. Results of Building Evaluations

Building	Number of Stories	Design Spectral Accel. (g)	ASCE 31 Shear Stress (psi)	ASCE 31 Allowable Shear (psi)	ASCE 31 Demand to Capacity Ratio	Shear Wall Area (sq ft)	Floor Area (sq ft)	Wall Index	Acceptable Wall Ratio (WR)
1	3	0.47	83 119	126	0.66 0.94	134 94	81,756	0.16 0.12	0.098
2	5	0.89	163 347	141	1.15 2.45	251 118	153,165	0.16 0.08	0.189
3	9	1.00	116 119	155	1.37 1.48	96 93	63,390	0.15 0.15	0.207
4	1	1.06	36 16	109	0.33 0.15	98 222	17,370	0.56 1.27	0.185
5	5	1.20	61 56	126	0.48 0.45	47 57	32,860	0.14 0.17	0.29

4.1 Building 1

The example building is a three-story structure, constructed in 1993, with a roughly rectangular footprint used as an office building with two levels of below-grade parking. The typical floor framing system comprises precast concrete planks with a reinforced concrete topping slab supported on concrete beams in one direction. The roof framing comprises a sloped cast-in-place concrete slab supported on cast-in-place concrete beams. Lateral forces are resisted by interior concrete shear walls near the central stairwell and elevator core and with small concrete wall piers around the perimeter of the building. There are several interior columns for gravity load support. The exterior walls are clad with granite panels. Interior partitions are framed with metal studs and gypsum wallboard. The building is located in an area of moderate seismicity. The design concrete strength is 4000 psi (27.6 MPa).

4.2 Building 2

The example building is a five-story structure used as an office building with two levels of below-grade parking. The building was built in 1998 and is roughly rectangular in plan with prestressed cast-in-place concrete floor slabs and roof slab. Lateral forces are resisted by interior concrete shear walls near the central stairwell and elevator core. There are several interior columns for gravity load support. The exterior walls are clad with a glass curtain wall. Interior partitions are framed with metal studs and gypsum wallboard. The building is located in an area of high seismicity. The design concrete strength is 5000 psi (34.5 MPa).

4.3 Building 3

The example building is a nine-story structure constructed in 2008, which is roughly rectangular in plan and is used as a residential building with one level of below-grade parking. The building floor and roof framing system consists of cast-in-place concrete. Lateral forces are resisted by concrete shear walls near the stairwell and elevator cores along one side of the building and exterior concrete shear walls along the opposite side of the building. There are several interior columns for gravity load support. The exterior walls are clad with a glass curtain wall on two sides and metal stud walls with cement plaster on the other two sides. Interior partitions are framed with metal studs and gypsum wallboard. The building is located in an area of high seismicity. The design concrete strength is 6000 psi (41.4 MPa).

4.4 Building 4

The example building is a one-story reinforced concrete structure that is roughly C shape in plan with roof diaphragm offsets, and is used as an emergency response center. The building was built in 1951 and is located in an area of high seismicity. The roof framing system consists of one-way flat slabs and pan joist slabs supported on concrete beams and walls. Lateral forces are primarily resisted by concrete shear walls and wall piers distributed around the building perimeter. There are a small number of interior columns for gravity load support. Exterior walls are bare cast-in-place concrete with large window openings between wall piers. The interior partitions comprise a combination of unreinforced concrete masonry and metal stud walls with gypsum wallboard. Since the interior partitions sit directly on grade and are isolated from the shear walls and columns, they do not contribute to the lateral load resistance of the building considerably.

4.5 Building 5

The example building consists of a pair of five-story residential structures a level of below-grade parking built in 2003 and located in an area of high seismicity. The two residential buildings are similar in plan dimensions with similar configurations of shear walls. The buildings are roughly rectangular in plan with prestressed cast-in-place concrete floor slabs and roof slab. Lateral forces are resisted by concrete shear walls located on each of the exterior walls. In the long direction, the exterior wall on one side of the building is solid for the first story of the building, this results in the second story shear walls being critical. There are several interior columns for gravity load support. The exterior walls are clad with a glass curtain wall. Interior partitions are framed with metal studs and gypsum wallboard. The building is located in an area of high seismicity. The design concrete strength is 4000 psi (27.6 MPa).

4.6 Chilean buildings

Following the 1985 Chile earthquake, a study of the performance of concrete buildings in Viña del Mar was performed [Wood 1991]. In that study, the structural characteristics of six typical buildings, including the ratio of wall cross sectional area to floor area was reported. That study acknowledged the good performance of buildings in the area and related the performance of the buildings to the typical design practice of providing a relatively large ratio of wall cross sectional area to floor area. This study relates the wall cross sectional area to the area of a typical floor, rather than considering the effect of the cumulative effect of the number of stories.

Using the data available for the six buildings in Viña del Mar, a Wall Index was calculated for each building in each direction. These representative buildings range in height from 12 stories to 23 stories. The typical unit weight of floors and the wall area to floor area ratio to floors above were taken from the data presented by Riddell et al [1987]. The spectral acceleration used in calculating the acceptable wall ratio was based on an idealized response spectrum determined using the recorded motion from the 1985 earthquake, determined for the approximate fundamental period of the building. The results are presented in Table 4.2.

Table 4.2. Wall Index and Acceptable Wall Ratios for Viña Del Mar Buildings

Building	No. of Stories	Wall Area / Typical Floor Area	Wall Index	Acceptable Wall Ratio (WR)
1	23	0.039 0.030	0.17 0.13	0.15
2	22	0.037 0.022	0.17 0.10	0.16
3	21	0.033 0.027	0.16 0.13	0.17
4	16	0.034 0.027	0.21 0.17	0.22
5	14	0.040 0.036	0.29 0.26	0.27
6	12	0.035 0.028	0.29 0.23	0.27

5. DISCUSSION

In the example U.S. buildings, the ASCE 31 demand-to-capacity ratios do not always compare well with the estimated risk of severe damage when the calculated Wall Index is compared to the threshold values proposed by Hassan.

The last column in Table 4.1 and Table 4.2 presents an acceptable wall ratio based on Eqn. 3.8. The calculated Wall Index for each building can be compared to the calculated acceptable wall ratio, good correlation between the estimated demand to capacity ratio using ASCE 31-03 and the ratio of wall index to the acceptable wall ratio is found. Where the ASCE 31-03 demand to capacity ratio for buildings in less than 1.0, the calculated Wall Index exceeds the acceptable wall ratio. Conversely, where the ASCE 31-03 demand to capacity ratio is greater than 1.0, the Wall Index is less than the acceptable wall ratio. The improvement in the acceptance criteria using the acceptable wall ratio is due to the factors in Eqn. 3.8, which includes the spectral acceleration, the average unit weight of the floor, and the strength of the concrete. These factors differ from that applicable to the buildings in Turkey evaluated in the development of the priority index method, as described below.

For the example buildings in Viña Del Mar, Chile, the Wall Index for each building is slightly below the calculated acceptable wall ratio in one direction. This would indicate that these buildings would not meet the acceptance criteria; however, the post-earthquake survey showed that the performance of the buildings were generally good. These differences are also discussed below.

5.1 Seismicity

The values of design spectral acceleration for the example U.S. buildings ranged from 0.47g to 1.2g. The priority index was based on the seismic demand from the 1992 Erzincan Earthquake, which produced peak ground acceleration values of 0.4g to 0.5g in Erzincan, where the damage data was collected. This corresponds to a short period spectral acceleration of 0.9g to 1.0g. This seismic hazard is similar to the required spectral acceleration values for many high seismic hazard areas in the United States. For buildings with lower seismic hazards, such as example Building 1, a smaller ratio of wall area to floor area above would be required.

It was noted earlier for the Chilean buildings with good seismic behaviour that the wall index in one direction is typically less than the acceptable wall ratio. One factor that may contribute to the discrepancy between the expected and observed damage for the Chilean buildings is the direction of shaking. The buildings may have been oriented such that the stronger and weaker directions of lateral load resistance for the buildings may have matched the recorded stronger and weaker peak acceleration directions. In our calculations for Table 4.2, the spectral acceleration used for calculating the acceptable wall ratio was based on the maximum ground motion direction for which the recorded peak ground acceleration was 0.36 g. In the perpendicular direction, the ground motion was 0.23 g. Using the lower ground acceleration would lead to acceptable wall ratios less than the calculated wall indices for the weaker lateral load resistance direction of the buildings. The idealized response spectrum used to calculate the spectral acceleration typically provides a larger value of spectral acceleration than the actual response spectrum from that earthquake

5.2 Floor weight

Concrete buildings in the United States tend to weigh less than comparable buildings in Turkey. The Chilean buildings are also generally heavier than U.S. buildings. This is partially due to the use of light weight interior partitions constructed with metal studs and gypsum board used in U.S. buildings as compared with the typical Turkish practice where clay tile partitions with plaster is used for interior partitions and in Chile where structural walls are often used as partitions between residential units. Buildings in the United States may also use light exterior curtain wall systems with glass and aluminium panels. Modern concrete buildings in the United States are also commonly constructed with post-tensioned floor slabs, which reduce the required thickness of the concrete slab for a given span. As a result, concrete buildings in the United States may have an average unit weight that is about two-thirds of the unit weight of buildings in Turkey and about 80 percent of the weight of buildings in Chile.

5.3 Concrete strength

The strength of concrete used in construction of buildings in the United States ranges from 4000 psi (27.6 MPa) to more than 8000 psi (55.2 MPa). In comparison, the average concrete strength for the building stock used in developing the priority index, as implied by Schmidt Hammer tests, is 14 MPa (2000 psi). For the Chilean buildings in Viña Del Mar, the design concrete strength was typically 3600 psi (24.8 MPa).

5.4 Acceptance criteria

Using a methodology where the acceptable wall ratio is based on a comparison of the ratio of wall area to the floor area above, the value will vary based on the seismic hazard, the average unit weight of the floor, and the strength of the concrete. For buildings in the U.S. which have typical values of concrete strength between 3000 psi (20.7 MPa) and 6000 psi (41.4 MPa) and average unit weights of floors between 1.0 psi (6.9 kPa) and 1.3 psi (8.3 kPa) and a design spectral acceleration value of 1.0 for buildings in areas of high seismicity, the acceptable wall ratio for concrete buildings would be between 0.16 and 0.30 for an acceptable wall ratio that equates to the Wall Index of the priority index.

The proposed methodology for an acceptable wall ratio for buildings in Turkey is compared to the equivalent threshold values proposed by Hassan for the priority index of 0.25 for high risk of severe damage and 0.50 for moderate risk of severe damage. Using the equivalent concrete strengths values reported by Hassan, the spectral acceleration values from the 1992 Ezrincan earthquake, and typical value of unit weight of floors, the acceptable wall ratio would be about 0.45. This compares well to the value for moderate seismic risk proposed by Hassan.

6. CONCLUSIONS

Seismic hazard mitigation includes evaluating existing buildings for seismic vulnerabilities. Since a large amount of the building stock throughout the world was designed and constructed prior to the implementation of modern seismic design procedures, a significant number of buildings are potentially vulnerable to damage due to earthquakes. Performing detailed seismic assessments of all older existing buildings is economically infeasible. Therefore, various screening techniques have been developed to quickly assess the seismic vulnerability of buildings so that the buildings with the greatest vulnerabilities can receive the appropriate mitigation resources.

Buildings with concrete floor framing that rely on concrete shear walls as the lateral force resistance are common building types. Simplified procedures for evaluating the seismic resistance of these types of buildings have been proposed by several earthquake engineers. Perhaps one of the most pragmatic, economical, and simplest assessment techniques among them is the priority index, which requires only limited knowledge of the building geometry as its input. The ASCE Tier 1 evaluation methodology, which is commonly used in the United States, as well as other countries, as a rapid evaluation procedure, is considerably more sophisticated in its treatment of the seismic vulnerabilities than the priority index. However, when the ASCE 31-03 criterion is rearranged, it is observed that the two methods are closely related. A comparison of predictions of seismic vulnerability using the priority index, after adjusting for concrete strength and seismic hazard, and ASCE 31-03 for the example U.S. buildings suggests good agreement between the findings of each method.

Our limited study suggests that the ASCE 31-03 Tier 1 evaluation methodology for rapid assessment of building seismic vulnerability can be expressed as a ratio of cross sectional area of shear walls to the total area of the floors above the level of the shear walls, which is similar to methodologies for evaluating concrete shear wall buildings that have been used in other countries. The ratio of wall area to the total area of floors above is compared to an acceptable wall ratio that is a function of the spectral acceleration, the average unit weight of the floors of the building, and the compressive strength of the concrete.

Using the ASCE 31-03 Tier 1 procedure as a basis for determining an acceptable wall ratio, can provide a technical justification to the Hassan Index developed for buildings in Turkey. As noted by Hassan and Sozen and confirmed in this study, the acceptance values proposed by Hassan are applicable only for a specific set of values of three variables for the building and would not necessarily be applicable elsewhere. The proposed screening procedure can be easily adapted to provide a screening tool for other geographic areas by providing specific values or ranges of values for the variables in the acceptable wall ratio equation.

It should be noted that the proposed procedure presents one aspect of a screening procedure for existing buildings. There are several other important characteristics of concrete shear wall buildings that should also be considered in a screening process such as the presence of vertical irregularities and horizontal irregularities. The critical vertical irregularity to be evaluated is the presence of discontinuous shear walls and the critical horizontal irregularity to be considered is torsion caused by in-plan eccentricity between the centre of mass and centre of rigidity of a building. The shear wall height to length ratio should also be considered in the evaluation process. A screening procedure should consider these characteristics in addition to the proposed procedure for evaluating the ratio of wall cross sectional area to area of floor above. Therefore, the training of experienced earthquake engineer, who can quickly identify such irregularities and their significance, cannot be overemphasized.

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