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- Technical Paper -

Proposal of Seismic Index of Low-rise Concrete Masonry Unit (CMU) Building in Afghanistan

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ABSTRACT

This paper applied the seismic evaluation method of the Japanese Standard on several recently constructed CMU (Concrete Masonry Unit) dominant buildings in Afghanistan. The obtained seismic indices, I_S, are compared with the maximum inter-story drifts of buildings calculated by Capacity Spectrum Method based on nonlinear static pushover analysis using STERA-3D software. As the result, an efficient and practical seismic evaluation method using a new seismic judgment index is proposed for Afghanistan low-rise buildings. Also, the paper recommends the CMU as an alternative for brick masonry in case of low-rise structures.

1. INTRODUCTION

Low-rise masonry structures are very popular in Kabul and major cities in Afghanistan. Except for government project, private buildings are designed without consideration of risk of earthquake, only following age-old methods without any modern building code or Afghanistan Structural Code (ASC) taken into consideration.

The Kiran-wa-Munjan earthquake with Magnitude 7.5 on 26 Oct 2015 killed 115 people and injured 538 people [statistics of the Afghanistan Government] that shows that the life and lives could be under severe threat of earthquakes in Afghanistan due to movement of the Indian plate over the Eurasia being at a rate of 4 cm/year. Therefore one of the problems is the existing low-rise structures which essentially require seismic evaluation to screen vulnerable buildings.

To identify the vulnerable buildings, it is necessary to define the seismic index (I_S) used in seismic evaluation method in Japan, for Afghanistan conditions.

The high demand of affordable housing is another challenging issue. In order to overcome this problem the government plans to construct a large number of low-rise and economically planned housings. In parallel to the seismic index proposal, this research also aims to introduce for both government and private sector that CMU (Concrete Masonry Unit) is a better alternative than Brick masonry.

2. SPECIMENS OF CMU BUILDINGS

Fifteen CMU dominant buildings have been selected as specimens for this study; nine specimens are two-story existing buildings and six specimens are three-story recently designed buildings.

Table 1 CMU Specimens Building Detail

Building No.	*Design f_m(MPa)*	*No. of Floor*	*Building Dimension*		*Shear Reinforcement of wall (single layer)*	*I_S index*		*Story Height (m)*
			L. (m)	*W. (m)*		*Long. D.*	*Trans. D.*	
01	10	2	20.8	20.6	D12@600mm	0.46	0.43	3.00
02	12	2	24.7	10.95	D14@600mm	0.84	0.83	3.00
03	13	2	29.6	27.2	D14@500mm	0.47	0.47	3.00
04	10	2	41.5	8.95	D12@400mm	0.45	0.45	3.00
05	12	2	35.2	14.00	D10@600mm	0.55	0.37	3.00
06	10	2	66.00	10.95	D12@500mm	0.37	0.15	4.00
07	10	2	46.20	10.95	D12@600mm	0.47	0.38	3.00
08	10	2	22.00	12.00	D12@600mm	0.38	0.45	3.00
09	10	2	44.00	10.00	D12@600mm	0.33	0.18	3.00
10	10	3	11.33	10.83	D10@400mm	0.76	0.32	3.20
11	10	3	13.00	10.80	D12@500mm	0.36	0.42	3.00
12	12	3	12.38	8.60	D12@500mm	0.50	0.35	3.20
13	10	3	12.38	11.50	D12@400mm	0.54	0.27	3.00
14	12	3	10.25	9.75	D12@400mm	0.65	0.38	3.00
15	12	3	24.70	10.95	D14@600mm	0.56	0.55	3.20

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The buildings have different reinforcement details that are commonly used in Afghanistan. All the buildings have the same wall thickness of 200mm but the masonry design compressive strengths (f_m) are different. And the nominal yielding strengths of reinforcing bars are equal 345MPa for all the buildings. An outline of the buildings is presented in Table 1. Figure 1 shows an architectural configuration for the specimen of CMU buildings No. 04.

It is assumed that all the specimens are located in very dense soil and soft rock that is classified as C-type in the Afghanistan Structural Code (ASC).

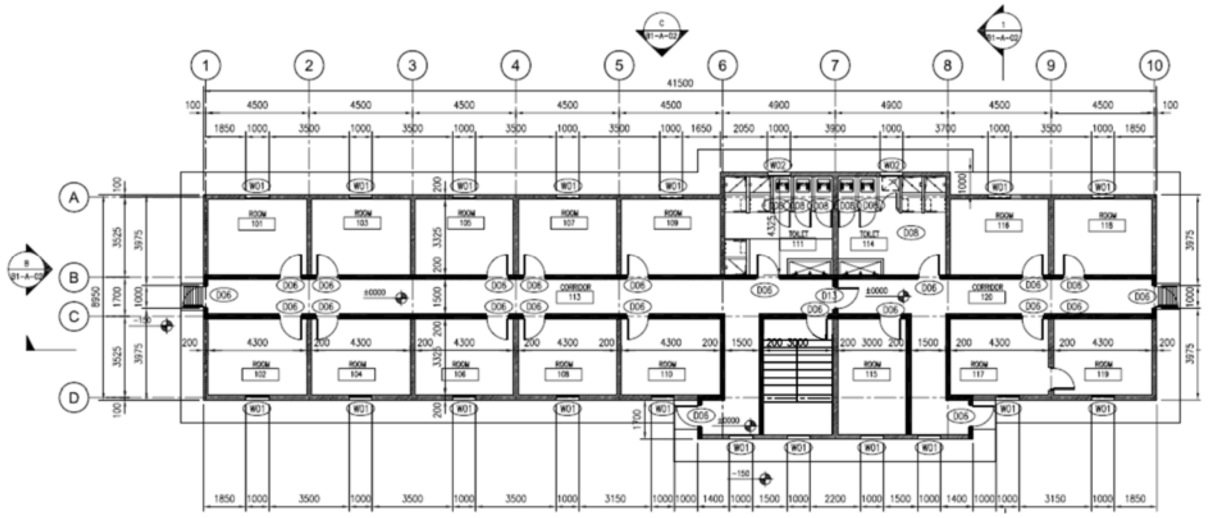


Fig.1 Ground Floor Plan of Building No.04

3. METHODOLOGY OF RESEARCH

Firstly, based on the Japanese Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings, 2001 [1], the seismic index (I_S) of each building for the first level screening is estimated.

Secondly, based on the Capacity Spectrum Method (CSM), the seismic performance of each individual building is calculated under the design spectrum spectra defined by the Afghan Structural Code and El Centro 1940 record. Finally, the results of screening method and those of capacity spectrum method are compared to find the appropriate seismic index (I_S) for low-rise buildings in Afghanistan.

4. SEISMIC SCREENING METHOD

Seismic Index (I_S) is defined in the Japanese Standard to evaluate the seismic performance of the low-rise and medium-rise RC buildings and is calculated by the following formula:

$$I_S = E_0 \times S_D \times T \tag{1}$$

$$E_0 = \frac{n+1}{n+i}(C_W + \propto C_C)\ F_W \tag{2}$$

$$C_W = \frac{\sum_{w=1}^{n}(A_{Wi} \times \ \tau_{Wi})}{\sum W}\ \ \beta_C \tag{3}$$

Where (I_S) is related to the basic seismic index (E_0), time index (T), and irregularity index (S_D). The time index is a modification factor of basic seismic index which evaluate the effects of cracks, deflection, and aging of building through inspection procedure defined in Japanese standard for seismic evaluation of existing building [1]. The irregularity index introduced to adjust the basic seismic index by measuring the effects of horizontal and vertical shapes, mass and stiffness irregular distribution of structure following engineering judgment. This study assumed both the irregularity index and time index ($T=S_D=1.0$).

And the basic seismic index (E_0), which present the seismic performance of building, is related to the strength index (C_W & C_c), the ductility index (F_W & F_c) of wall or columns and the story-shear modification factor. The Japanese Standard defines three screening procedures for estimating the basic seismic index (E_0). This study adopted the first level of screening to calculate the basic seismic index.

In case of the CMU dominant buildings, the walls totally sustain the seismic load and the building has no column (C_C=0). Equation (3) practiced to estimate strength index of wall (C_W). In addition, the ductility index of CMU wall (F_W) was assumed to be 1.0 because of the following reason. According to the study by P. B. SHING [8], the deformation capacity of the masonry shear wall depends on the final damage mode. And in case of shear failure mode, the deformation capacity is around 1/250 drift angle that corresponds to F_w=1.0. Since the vertical reinforcement ratio of the specimens of CMU building is relatively small, we assumed the failure mode is shear and adopted F_w=1.0.

As for the average stress at the ultimate state of wall, (τ_W), the Akira MATSUMURA [4] concluded that the maximum shear stress is more than 1.6MPa for reinforced masonry wall. So, this study adopted (τ_W=1.0MPa) considering safety margin. Conventionally, the β_C applied for CMU structure based on nominal compression strength (f_m) of masonry. Where, in case ($f_m \le$ 20Mpa) it is equal (β_C=f_m/20), and for the (f_m>20Mpa) the ($\beta_C = \sqrt{f_m/20}$). And (A_{wi}) and (α) are area of wall and modification factor of column at ultimate deformation [1]. $\sum W$, is the total permanent load sustained by concerned story plus live load for seismic calculation.

Table 2 Seismic Index Parameter

Build. No.	$\sum W$	$\sum A_w$ (m^2)		β_C	Wall strength index (C_W)	
	MN	*L. dir*	*T. dir*		*L. dir*	*T. dir*
01	10.2	9.44	8.88	0.50	0.46	0.43
02	7.1	10.08	9.87	0.60	0.84	0.83
03	19.3	14.08	14.10	0.68	0.47	0.47
04	12.0	18.80	14.07	0.50	0.45	0.45
05	11.8	10.78	7.32	0.60	0.55	0.37
06	17.3	12.70	5.07	0.50	0.37	0.15
07	13.0	12.24	9.87	0.50	0.47	0.38
08	6.3	4.85	5.66	0.50	0.38	0.45
09	11.4	7.48	4.20	0.50	0.33	0.18
10	3.6	5.57	2.30	0.50	0.76	0.32
11	5.7	4.08	4.78	0.50	0.36	0.42
12	4.2	3.52	2.47	0.50	0.50	0.35
13	5.5	6.00	2.96	0.50	0.54	0.27
14	5.5	5.95	3.50	0.60	0.65	0.38
15	10.7	10.08	9.87	0.60	0.56	0.55

Note 1: Time index and Irregularity index assumed 1.00 for all buildings.
Note 2: The calculated (Is) present by Table 1.
Note 3: The exact construction year of specimens buildings are unknown, but the buildings are constructed between 2001 till 2012.

5. CAPACITY SPECTRUM METHOD

5.1 Wall Element Model in STERA-3D

The specimens of CMU building were analyzed by STERA-3D software, which is coded by one of the author [6].

The software has the capability to input the force-deformation parameters directly for structural elements. Whereas, the hysteresis model of masonry elements defined as the poly-linear slip model [6], in Figure 2. The yield shear force (Q_y) assumed equal to CMU wall shear capacity (V_{um}) in Equation (4) that is speculated in the Building Code Requirements for Masonry Structure [3]. And the crack shear force (Q_c=1/3Q_y) is estimated as one-third of the yield shear force. The ultimate shear force (Q_u=Q_y) assumed equal to yield shear force.

Furthermore, the yield shear deformation and ultimate shear deformation (γ_y=1/250) and (γ_u=1/100) are assumed, respectively. And the cracked shear deformation is calculated relative to the initial stiffness, in Equations (5) and (6) [6].

$$V_{um} = 0.083\left[4\ .0 - 1.75\ \left(\frac{M_u}{V_u d_v}\right)\right] A_v \sqrt{f'_m}\ + 0.25 P_u \qquad (4)$$

$$\gamma_c = \frac{Q_c}{k_0} \qquad (5)$$

$$k_0 = \frac{2Q_y}{\gamma_y} \qquad (6)$$

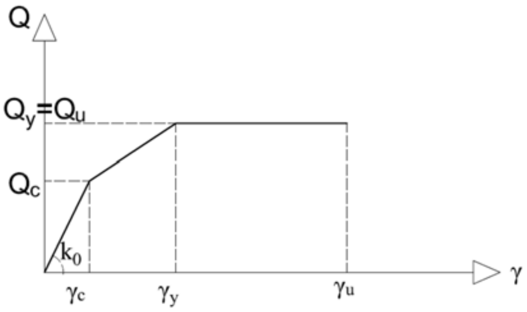


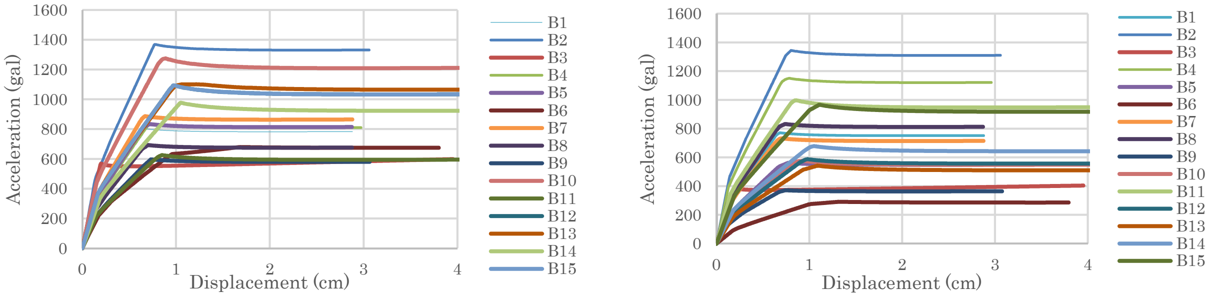
Fig.2, Shear-Deformation Relation

In Equation (4), M_u and V_u are the ultimate moment and the shear forces in (N-mm) and (N) respectively, f'_m and f_y are the nominal compressive strength of masonry and yield strength of reinforcement in (MPa), Pu is the ultimate axial load in (N), d_v and A_v are the depth of masonry wall in the direction of shear considered and the cross-sectional area of shear reinforcement in (mm) and (mm^2), respectively. M_u & V_u, due to gravity load and lateral load, calculated following ASC seismic section and$\left(\frac{M_u}{V_u d_v} \leq 1\right)$ should not exceed 1.0.

5.2 Pushover analysis

The capacity curves of CMU buildings in longitudinal and transverse directions, which represent the relationship of inter-story drift and story shear in acceleration divided by the mass, obtained by the nonlinear push-over analysis from STERA-3D, are presented in Figure 3.

Following the Japanese Standard for Capacity Spectrum Method (CSM), the capacity curves are converted into bi-linear curves to have the same dissipation energy.



a) Longitudinal direction

b) Transverse direction

Fig.3 Capacity Curve of Specimen Building

5.3 ASC & El Centro Response Spectrum

Afghanistan Structural Code (ASC) presents the mapped spectral acceleration for 1Hz and 5Hz with 5% of critical damping. These maps are available for 2%, 5% and 10% of probability of exceedance in 50 years [2].

Using these maps, for the specimens building located in Kabul region, the maximum considered earthquake spectral acceleration is obtained for short period (S_S=1.31g) and for one-second period (S_1=0.52g). Then, by applying the site modification factor (1.0 for short-period & 1.3 for 1-sec period) and design reduction factor (2/3 of mapped parameter), the spectral acceleration converted to design spectral acceleration (S_{DS}=0.87g and S_{D1}=0.45g). Following the ASC [2] definition, and Equations (7), (8), (9), (10) and (11), the response Spectra plotted as shown in Figure 4.

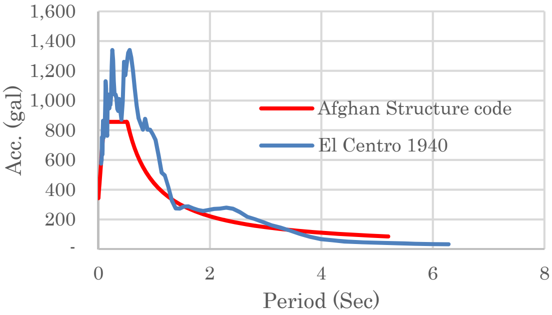


Fig.4, ASC and El Centro Response Spectra

$$S_a = S_{DS}\left[0.4 + 0.6\left(\frac{T}{T_0}\right)\right] \dots\dots for\ \ 0 < T < T_0 \tag{7}$$

$$S_a = S_{DS}\ \ \dots\dots\dots\dots\dots\dots\dots\dots for\ \ T_0 < T < T_s \tag{8}$$

$$S_a = \frac{S_{D1}}{T} \dots\dots\dots\dots\dots\dots\dots.\dots\dots for\ \ T_s < T < T_L \tag{9}$$

$$T_0 = 0.2\frac{S_{D1}}{S_{DS}} \tag{10}$$

$$T_S = \frac{S_{D1}}{S_{DS}} \tag{11}$$

In Equation (9), the long period (T_L) assumed five seconds. Figure 4, also presents the response spectrum of the El Centro 1940 NS component record. It is seen that the El Centro 1940 has larger spectral amplitude than ASC code.

5.4 Performance Point

In the Capacity Spectrum Method, the capacity curve of the building obtained by the nonlinear push over analysis in Section 5.2 and the demand spectrum of ASC and El Centro 1940 in Sections 5.3 are both used to estimate the performance point, which describe the maximum nonlinear displacement of the building. Equation (12) is the equivalent damping factor (h_e) estimated by the empirical formula as a function of the ductility factor (μ), and Equation (13) is the spectral reduction factor (F_h) according to the damping factor. The performance point is defined as the intersection between capacity curve and reduced response spectrum obtained by an iterative procedure.

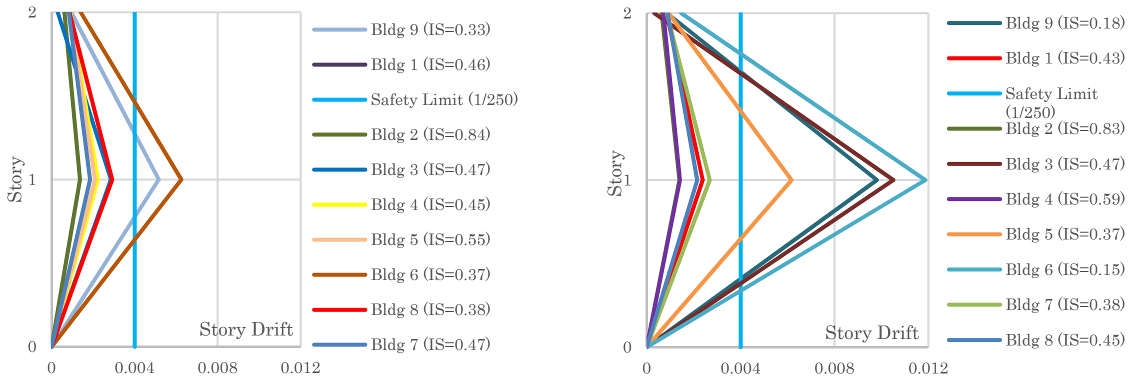
$$h_e = 0.25\left(1 - \frac{1}{\sqrt{\mu}}\right) + 0.05 \tag{12}$$

$$F_h = \frac{1.5}{1 + 10\ \ h_e} \tag{13}$$

5.5 Distribution of Maximum Inter-Story Drift

From the performance point estimated from the Capacity Spectrum Method in Section 5.4, going back to the pushover analysis, corresponding distribution of the maximum inter-story drift of the building is obtained.

Figures 5a and 5b show the maximum inter-story drift of two story CMU buildings for longitudinal and transverse directions for the ASC response spectrum. The blue straight line indicates the safety design limit (1/250). In longitudinal direction (Figure 5a), the specimen buildings No. 6 (I_S=0.37) & No. 9 (I_S=0.33) with are able to resist the load within the safety story drift. Whereas, in transverse direction (Figure 5b), the buildings No.3 (I_S=0.47), No. 5 (I_S=0.37), No.6 (I_S=0.15) and No. 9 (I_S=0.18) have reached the story drift limit of (1/250).



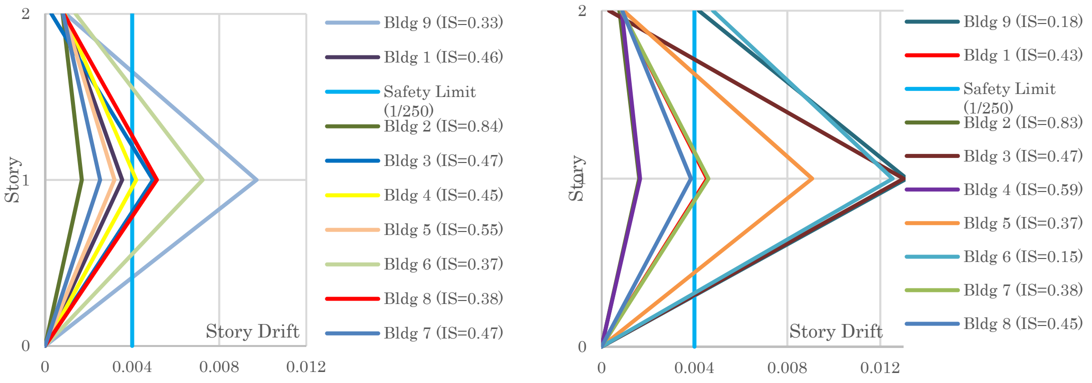
a) Longitudinal direction

b) Transverse direction

Fig.5 Maximum Inter-story Drift Angle for ASC Design Response Spectrum (2 story structure)

In the similar way, Figures 6a and 6b show the maximum inter-story drift angle of two story CMU buildings for both directions for the El Centro 1940 response spectrum. Comparing to the ASC results, the story drifts in this case are generally larger. And the transverse direction for both demand spectrum has weak performance compared to the longitudinal direction.

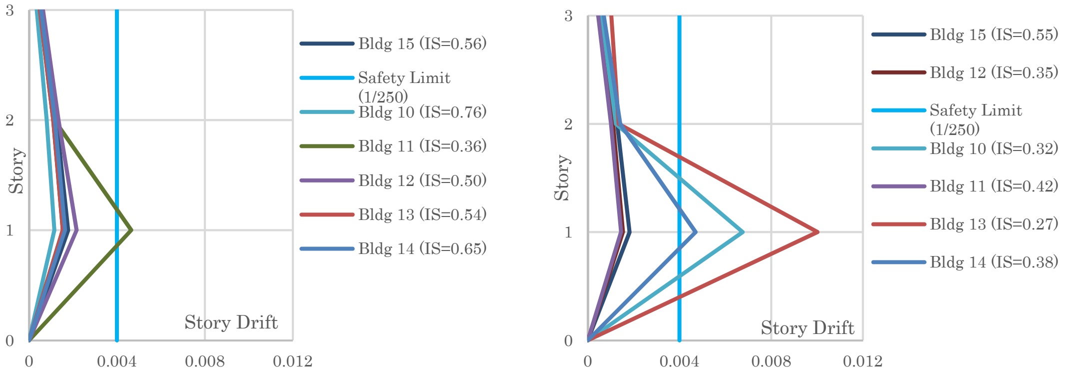
Figures 7a and 7b show the maximum inter-story drift angle of three-story CMU buildings for the ASC response spectrum. In longitudinal direction, the performance of buildings is sufficient except building No. 11 (I_S=0.36). But in transverse direction, buildings No. 13 (I_S=0.27) has the weakest performance which reaches 1/100.



a) Longitudinal direction

b) Transverse direction

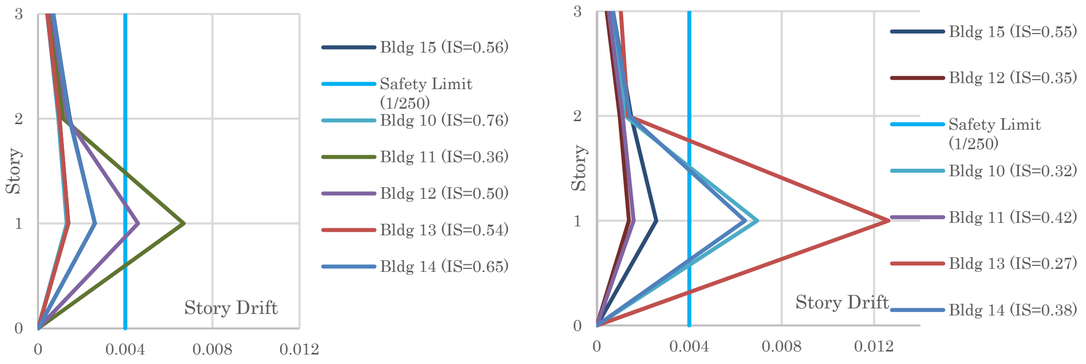
Fig.6 Maximum Inter-story Drift Angle for El Centro 1940 Response Spectrum (2 story structure)



a) Longitudinal direction

b) Transverse direction

Fig.7 Maximum Inter-story Drift Angle for ASC Response Spectrum (3 story structure)



a) Longitudinal direction

b) Transverse direction

Fig.8 Maximum Inter-story Drift Angle for El Centro 1940 Response Spectrum (3 story structure)

In the similar way, Figures 8a and 8b show the maximum inter-story drift angle of three-story CMU buildings in both directions, for the El Centro 1940 response spectrum. Comparing the ASC results, the story drifts in this case are generally larger.

In most of the cases, buildings with large seismic index are able to satisfy the safety design limit (1/250). However, in some rare cases, buildings with similar seismic index have different results. For instance, building No. 6 and building No. 8 with similar seismic index of 0.37 and 0.38, respectively, in longitudinal direction, have different seismic performances as shown in Figure 5a. Unlike the building No. 8, which satisfies the safety drift limit, the building No. 6 is not able to satisfy the limit. This difference of the performance is related to the amount of shear capacity and reinforcement, and the architectural configuration of CMU walls. Since, the (*Is*) index for first level of inspection neglects the reinforcement contribution, two buildings show similar seismic (*Is*) index.

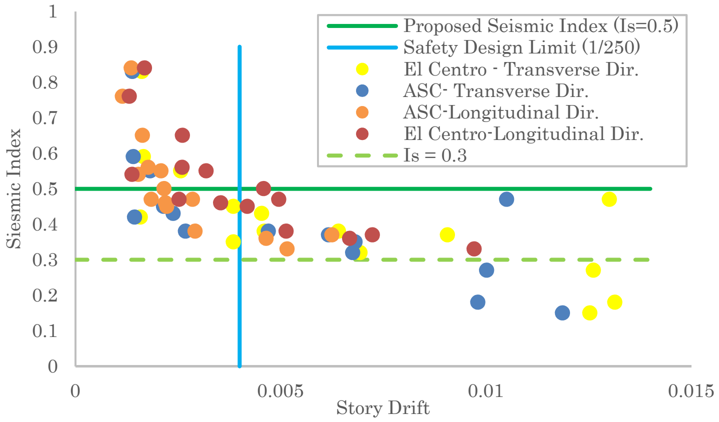


Fig.9 Seismic Index vs Inter-story Drift Angle

Figure 9 shows the relationship between the maximum story drift and seismic index. From this figure, the buildings with seismic index equal or larger than (≥0.5) are able to confirm the Safety Drift Limit (1/250). Therefore, the CMU buildings which satisfy the seismic index *Is*=0.5 have enough strength to be alternative for brick masonry in Afghanistan.

6. CONCLUSIONS AND RECOMMENDATION

(1) The research found that the buildings with ($I_S<0.5$) will suffer damage. Therefore, this study proposes $I_S=0.5$ as the seismic safety index for the first level of screening of CMU buildings in Afghanistan.

(2) From the seismic performance of 15 CMU buildings, the seismic performance of 3-story buildings reveals, CMU could be a good alternative of infill brick masonry for Afghanistan.

(3) The 'seismic evaluation method of Japanese Standards' is a practical tool for assessment of existing buildings in Afghanistan.

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