Technical Note

This is an extended version of the paper presented in SEE7 conference, peer-reviewed again and approved by the JSEE editorial board.

Comparison of Seismic Safety and Functionality of Low Rise Important Buildings Designed by the First Three Editions of Iranian Seismic Code

Ali Saadaie Jahromi[1] and Kiarash Nasserasadi[2*]

1. M.Sc. Graduate in Structural Engineering, University of Zanjan, Zanjan, Iran
2. Assistant Professor of Civil Department, University of Zanjan, Zanjan, Iran, and Member of Iranian Earthquake Engineering Association,
* Corresponding Author; email: nasserasadi@znu.ac.ir

Received: 13/06/2016
Accepted: 29/01/2017

ABSTRACT

Buildings with high degree of importance such as hospitals, police stations, fire stations and other vital facilities play a crucial role in crisis and risk management of cities. Therefore, special attention should be paid to design and construction of these buildings in order to maintain their performance during and after the earthquake. Important buildings in Iran is designed according to the Iranian code of practice for seismic resistant design of buildings (ISC). So far, four editions of the code have been published. In this study, improvement of seismic safety of important buildings in the first three editions of ISC are examined and the results are compared with an acceptable level of safety. In this study, a 3-story steel moment resisting frame is selected and designed based on different editions of ISC for high seismic zones. The seismic fragility functions of frames are estimated in all soil classifications of the code. The probability of failure of frames are estimated for Tehran and Tabriz, two major cities located in high seismic zones. Results shows a good improvement in safety of different frames in recent editions of ISC, especially from the first to the second editions due to mandatory of ductile design and increase of the design forces. However, the functionality and safety of buildings do not satisfy the minimum requirements of the code. In addition, the results indicated that the probability of failure of frames located in softer soil types is higher than others. This show that within any code edition, a constant limit of safety was not provided in different soil types. Therefore, an improvement in the spectral acceleration of different soil type is required.

Keywords:
Seismic risk;
Important buildings;
Seismic code;
Fragility function

1. Introduction

Iranian seismic code (ISC) or standard number 2800 [1], which first introduced just before Manjil-Rudbar earthquake in 1988, has been used for designing of buildings and other facilities. So far, four editions of the code are introduced. By introduction of each code's edition, it is expected that the quality of construction to be improved and the vulnerability of structures is reduced. Nevertheless, the experience of recent earthquakes such as Varzeghan (2012), demonstrate that some structures, especially important buildings such as hospitals are vulnerable to earthquakes. Although many improvements in design requirement of important buildings have been introduced in the recent versions of ISC, some studies have shown that these buildings still do not satisfied the ISC's criteria.

Motamed Sahebi [2] studied the effect of regularity in very important building designed based on ISC. Besides, Mahmoudi and Ghobadi [3] studied the performance of important buildings which do not remain operational after large earthquakes. The uncertainties in the application of *R* factor in static design and vulnerability seismic evaluation of important buildings are studied by Behnamfar and Nafarieh [4] and Shakib [5]. They concluded that constant R factor make very important buildings vulnerable due to earthquake events. The results have shown that the performance of important buildings designed by the code are not suitable.

To study the seismic risk of important buildings from the probabilistic point of view, the seismic performance and safety of important buildings in the first three editions of ISCs in high seismic hazard zone and all soil types are estimated and compared. For this purpose, a three-story steel MR frame is selected and designed for the first three editions of ISC in all soil type. The fragility functions of the frames are developed for two damage states: losing functionality and collapse. The probability of selected damage state is estimated for two cities of Tehran and Tabriz that are located in a high seismic zone.

2. Development of Editions of Iranian Seismic Code

Iranian Seismic Code (ISC No. 2800 [1]) was first introduced just before Manjil-Rudbar earthquake in 1988. Since then, four different editions of the code have been introduced that contain significate improvement in the ductility level of structures and applied the load by refining the code spectrum. In all editions of the code, the seismic base shear are evaluated by $V = CW$ in which W is the total effective weight of structure and C is the seismic coefficent calculated by $C = ABI / R$. The parameters of seismic coefficients for all three editions of ISC have been compared in Table (3) in Appendices.

The main differences in the design of important buildings are: the response spectrum (B coefficient) shown in Figure (1), seismic importance factor (I), and response modification factor (R). A quick look at Figure (1) indicated that the code spectrum has increased, especially in the third edition of the code. The importance factor for important buildings, which

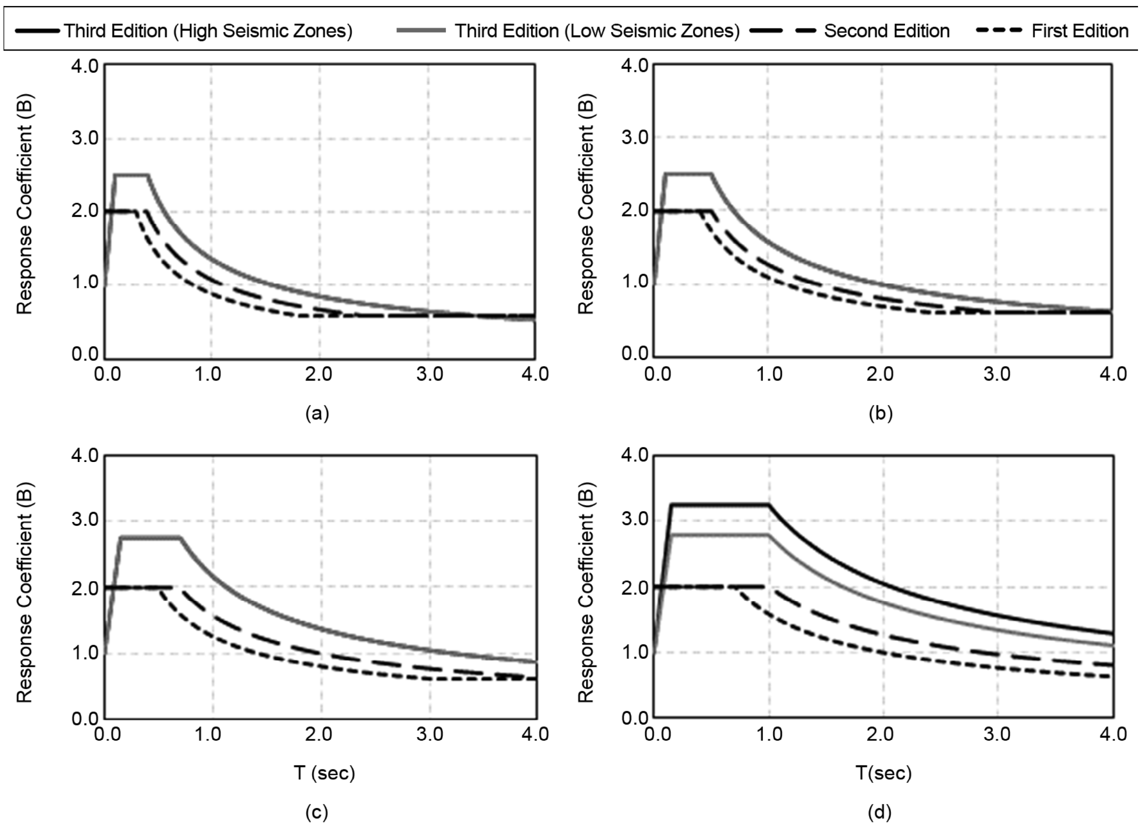

Figure 1. Comparison of seismic response spectrum in different editions of Iranian seismic code (a) Soil I; (b) Soil II; (c) Soil III (d) Soil IV.

is the main focus of this paper, was similar in the first and the second editions of ISC (I =1.2) and increased in the third edition (I = 1.4). Design of ductile frames of important buildings was mandatory in the third edition of the code. In addition, the ductility details have been improved in the latest editions of the code that results in higher ductility.

3. The Study Methodology

In this study, the probability of two different damage states of structures, the disruption of functionality (or slight damage state) and collapse (or complete damage state), are evaluated by developing the fragility function of structures by the stochastic approach (see reference [6] for full description of the methodology). For this purpose, the following steps should be taken:

1. A three-story moment resisting frames (MRF) was selected and designed based on different editions of ISC.
2. The fragility curves of designed frames were evaluated by analytical method through numerous nonlinear dynamic analysis containing the following steps:
   a) Select damage measure that is Inter-Story Drift in this study.
   b) Estimate the distribution of damage measure through numerous nonlinear dynamic analysis.
   c) Select different damage thresholds.
   d) Evaluate the exceeding probability of damage measure from different damage states.
   d) Fit fragility function to the results.
3) The seismic risk of frames that is estimated by multiplying the hazard curve and fragility function is evaluated for two different high risk zone in Iran: Tabriz and Tehran.
4) The results are compared with the acceptance damage probability given in literatures.

The detail of each step is given in the following sections.

4. Selection and Design of Building Frames

A 3-bay, 3-story steel frame located in high seismic zone has been selected for study, which is illustrated in Figure (2). The frames are designed for different soil condition in high seismic zone based on each seismic code. Standard European sections were used in the design of section (I shape for beams and H shape for columns). Due to the similarity in the result of designed sections for different cases, all designed frames were fallen into three types, which illustrates in Table 4 in Appendices. As it can be seen, the designed frames based on 2nd and 3rd edition of ISC are similar.

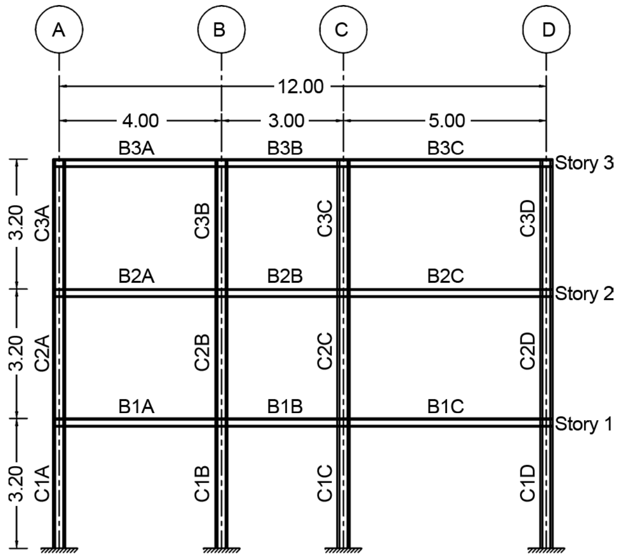

Figure 2. View of selected 3-story frames from a very important buildings.

5. Fragility Function Development

To develop the fragility function, as described earlier, the response distributions of frame were evaluated through multi-stripe analysis (MSA) [7] by OpenSees [8]. To evaluate the response distribution in each four soil classification, numerus ground motions in different soil classification have been selected from PEER strong ground motions database, which consisted of 37 in soil I, 44 in soil II, 45 in soil III and 37 in Soil IV.

Medians and deviation of ISD distribution of frames in all versions of ISCs and different soil types have been plotted as a function of PGA in Figure (3). It can be observed from the figure that the response distribution of second and third editions are very close in all soil classification. While response distribution of first edition have higher value in the all IM. In addition, soil types have significant effect on distributions of response. The median of response in softer soil are higher. In general, the higher displacement can be interpreted as higher vulnerability that will be projected in the fragility functions.

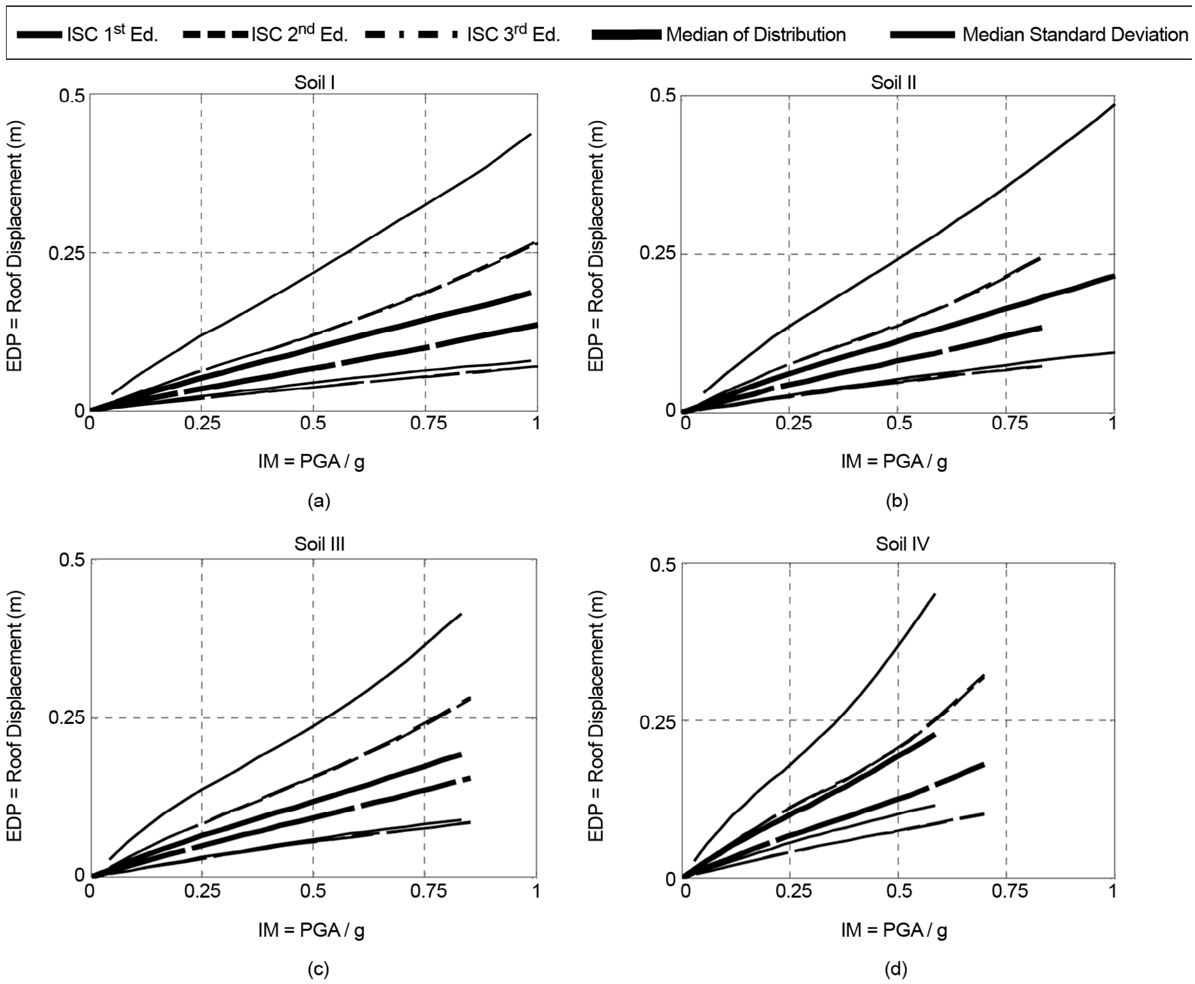

Figure 3. Median of ISD distribution for different editions of ISC. (a) Soil I, (b) Soil II, (c) Soil III, (d) Soil IV.

In this study, the fragility functions is estimated as a function of peak ground acceleration (PGA) as intensity measure. Since two damage state of slight for the loss of functionality and complete damage for the collapse of structure are considered, the fragility function of these two damage states are developed. For this purpose, the exceeding probability of damage measure from the threshold of these damages taken from HAZUS's methodology [9] (see Table 4) are estimated and fragility function of Eq. (1) was fitted to the results.

$$P(D > d_i \mid pga) = \Phi\left(\frac{\ln(pga/pga_{mi})}{\beta_i}\right) \tag{1}$$

In which, $P(D > d_i \mid pga)$ is fragility function or exceeding probability of damage (D) in structure from any damage state d_i (i.e. loss of functionality or collapse) in any given pga, pga_{mi}, and β_i are the fragility parameters called median and lognormal deviation of ith damage state respectively. These parameters are estimated by Nasserasadi et al [6] methodology for studied frames and are given in Table (2).

Table 1. Typical inter story drift ratio threshold represent in HAZUS [8].

ISC No. 2800	Disruption of Functionality (Slight Damage)	Collapse (Complete Damage)
First Edition	0.005	0.080
Second Edition	0.005	0.060
Third Edition	0.005	0.040

In order to evaluate the seismic risk of different frames, the probability of exceeding of damage from two mentioned damage states are evaluated. The exceeding probability is estimated by multiplying the seismic hazard by the fragility function in probabilistic manner. A simplified formulation can be used for the estimation of this probability given in Eq. (2) [10].

Table 2. Parameters of developed fragility functions in three code editions and various soil types for two damage states: loss of functionality and collapse.

Editions of ISC	Soil Classification	Damage State: Loss of Functionality (Slight)		Damage State: Collapse	
		PGA_{m1}	β_1	PGA_{m2}	β_2
First Edition	I	0.1812	1.0647	1.4296	1.0108
	II	0.1462	0.9864	1.4308	1.0017
	III	0.1353	0.9411	1.2384	0.8633
	IV	0.0820	0.8144	0.7266	0.8310
Second Edition	I	0.2727	0.8037	2.3189	0.6907
	II	0.2077	0.7946	2.2428	0.7147
	III	0.1762	0.7724	2.2131	0.7178
	IV	0.1331	0.6809	1.2956	0.6183
Third Edition	I	0.2727	0.8037	2.7509	0.6732
	II	0.2077	0.7946	2.7450	0.6967
	III	0.1762	0.7724	2.6395	0.6824
	IV	0.1331	0.6809	1.5442	0.6036

$$P(D > d_i) = K_0 PGA_{mi}^{-K} e^{\frac{\beta_i^2 K^2}{2}} \quad (2)$$

where $P(D > d_i)$ is the exceeding probability from any damage state, K_0 and K are the parameters of hazard curve, pga_{mi} and β_i are the parameter of fragility function for given damage state i_{th}.

In this study, the exceeding probability of damage are estimated for Tehran and Tabriz that are located in high seismic zones. Seismic hazard curve of Tehran and Tabriz and fitted function (K and K_0 as suggested by Ghafory-Ashtiany and Nasserasadi [11]) are shown in Figure (4).

The seismic risk of studied frames has been calculated using Eq. (2) and shown in Figure (5). As illustrated in the figure, a suitable improvement on the reduction of probability of loss of functionality and collapse of structure is observed in newer editions of ISC, especially from the first to second edition of code and on the collapse state. This is mainly due to mandatory of using the ductile MR frame for the important buildings in the second edition of the code and the increasing of the design forces that applied by increasing of earthquake spectra of different soils.

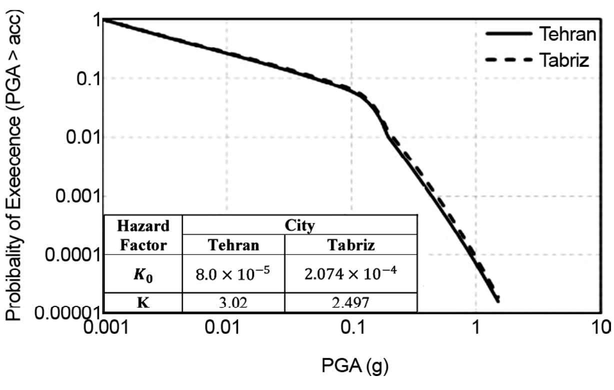

Figure 4. Hazard Curves for Tehran and Tabriz [11].

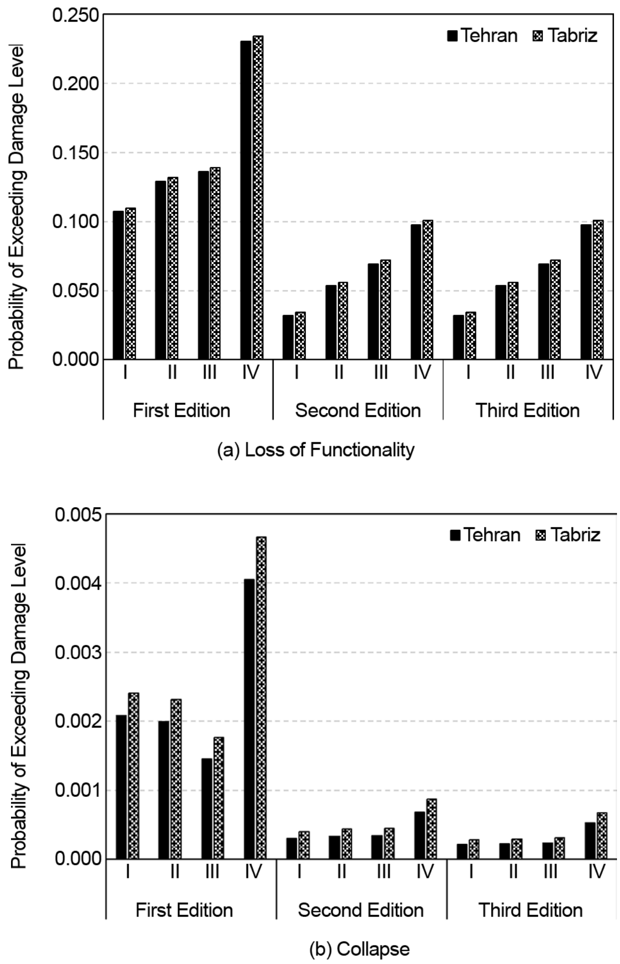

Figure 5. Comparison of exceeding probability of damage from loss of functionality and collapse in important buildings located in Tehran and Tabriz designed based on different editions of ISC in all soil classification (I, II, III and IV).

Nevertheless, the probability of loss of function in important buildings is in order of 10-2 and 10-1. Similarly, the probability of collapse is in the order of 10-3. Both values are not acceptable from the code's point of view. This fact also demonstrated in the literatures (such as [3, 5]) in which, indicated that the performance of very important buildings is not satisfied ISC's criteria. Therefore, to improve the performance of these buildings, a special attention should be paid on the design criteria of important buildings.

Soil type has significant effect on seismic safety of buildings. The buildings located in the softer soils have higher seismic risk that means they are more vulnerable. This means that the spectral acceleration of the codes for different soil types needed to be modified to maintain similar safety for all types of buildings. The results are similar in two cities of Tehran and Tabriz. Still, the probability of failures of buildings in Tabriz is higher than Tehran, which is an indication of higher risk in Tabriz.

6. Conclusions

In this paper, the seismic risk of low raised important buildings designed based on different editions of ISC are compared. A steel resisting moment frame is selected and designed according to different editions of ISCs. The probability of exceeding of damage from two damage stages of slight (loss of functionality) and collapse are estimated in Tehran and Tabriz. Fragility functions of studied frames are developed by analytical procedure through nonlinear dynamic analysis subjected to numerous ground motions in all soil types. It can be concluded that:

- The probability of loss of functionality and collapses are significantly higher than expected for all designed buildings, which indicates more consideration in design code.
- Seismic safety of important buildings in the second and third editions of ISC have been improved significantly due to the ductile design of frames and higher design force.
- In all editions of the code, structures designed for softer soil types, experiences more risk, which indicates that a constant margin of safety was not provided for different soil types. More research in this regard is needed.

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Appendix

Table 3. The most changes in the seismic force coefficient's parameter in the all three editions of ISC [1]. The bold ones are used for the important buildings

Iranian Seismic Code 2800		Third Edition	Second Edition	First Edition
Seismic Zone Factor (A)	Very high risk	0.35	0.35	-
	High risk	0.30	0.30	0.35
	Moderate risk	0.25	0.25	0.30
	Low risk	0.20	0.20	0.25
Seismic Importance Factor (I)	Very Important	**1.4**	-	-
	Important	1.2	**1.2**	**1.2**
	Moderate	1.0	1.0	1.0
	Slight	0.8	0.8	0.8
Response Modification Coefficient (R)	Steel Moment Resisting Frame	Ordinary Sway: $R = 5$ Intermediate Sway: $R = 7$ Special Sway: $\mathbf{R = 10}$	Ordinry Sway: $R = 6$ Special Sway: $\mathbf{R = 10}$	Ordinary Sway: $\mathbf{R = 6}$ Intermediate Sway: $R = 8$

Table 4. The typical designed frames for this study.

Edition of ISC 2800			First	Second	Third
Column Sections	3rd Floor	**C3A**	HE140B	HE220B	HE220B
		C3B	HE120B	HE280B	HE280B
		C3C	HE160B	HE300B	HE300B
		C3D	HE180B	HE300B	HE300B
	2nd Floor	**C2A**	HE160B	HE220B	HE220B
		C2B	HE180B	HE280B	HE280B
		C2C	HE180B	HE300B	HE300B
		C2D	HE160B	HE300B	HE300B
	1st Floor	**C1A**	HE160B	HE220B	HE220B
		C1B	HE200B	HE280B	HE280B
		C1C	HE200B	HE300B	HE300B
		C1D	HE180B	HE300B	HE300B

Edition of ISC 2800			First	Second	Third
Beam Sections	3rd Floor	**B3A**	IPE270	IPE270	IPE270
		B3B	IPE220	IPE200	IPE200
		B3C	IPE330	IPE330	IPE330
	2nd Floor	**B2A**	IPE270	IPE270	IPE270
		B2B	IPE240	IPE200	IPE200
		B2C	IPE330	IPE330	IPE330
	1st Floor	**B1A**	IPE270	IPE270	IPE270
		B1B	IPE270	IPE200	IPE200
		B1C	IPE330	IPE330	IPE330