RELIABILITY AND QUANTITY BASED EVALUATION OF STRUCTURAL PROPORTIONS OF SEVERAL HIGHWAY PRECAST PRESTRESSED I GIRDER BRIDGES DESIGNED IN AN EARTHQUAKE REGION

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RELIABILITY AND QUANTITY BASED EVALUATION OF STRUCTURAL PROPORTIONS OF SEVERAL HIGHWAY PRECAST PRESTRESSED I GIRDER BRIDGES DESIGNED IN AN EARTHQUAKE REGION

submitted by **İLDEM TOKER** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Ahmet Türer
Head of Department, **Civil Engineering** ________________

Prof. Dr. Alp Caner
Supervisor, **Civil Engineering, METU** ________________

Examining Committee Members:

Prof. Dr. Ahmet Yakut
Civil Engineering, METU ________________

Prof. Dr. Alp Caner
Civil Engineering, METU ________________

Prof. Dr. Uğurhan Akyüz
Civil Engineering, METU ________________

Prof. Dr. Murat Altuğ Erberik
Civil Engineering, METU ________________

Assoc. Prof. Dr. Burcu Güldür Erkal
Civil Engineering, Hacettepe University ________________

Date: 23.08.2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: İldem Toker

Signature:

ABSTRACT

RELIABILITY AND QUANTITY BASED EVALUATION OF STRUCTURAL PROPORTIONS OF SEVERAL HIGHWAY PRECAST PRESTRESSED I GIRDER BRIDGES DESIGNED IN AN EARTHQUAKE REGION

Toker, İldem
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Bridges located in earthquake regions are generally designed with using force or displacement methods specified in American and European Codes which are AASHTO and Eurocode basically. Current vision for design purposes proposes that reliability analysis requirements determine the loads, load factors and load combinations by means of statistical approach. The significant uncertainty about earthquake load resulted in use of different design approaches per different specifications. Different design methods and specifications can yield to different material quantity and reliability results. Most of the bridge earthquake design is based on a commonly preferred method that is response spectrum analysis method. The aim of the study is to identify a relation between seismic design reliability and quantity of structural members since there is a limited research on this subject. In this scope, one hundred and sixty two different bridges are analysed for six different seismic cases using finite element analysis program SAP2000. The detailed design calculations are prepared for columns.

Keywords: Response Spectrum Analysis, Earthquake Region, Quantities, Reliability

ÖZ

DEPREM BÖLGELERİNDE ÇEŞİTLİ PREFABRİK ÖNGERMELİ I KİRİŞLİ KARAYOLU KÖPRÜLERİ İÇİN YAPISAL KISIMLARIN GÜVENİLİRLİK VE METRAJ TEMELİNDE DEĞERLENDİRİLMESİ

Toker, İldem
Yüksek Lisans, İnşaat Mühendisliği
Tez Danışmanı: Prof. Dr. Alp Caner

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Deprem bölgelerinde yer alan köprüler genellikle Amerikan ve Avrupa şartnamelerinde (AASHTO ve Eurocode) belirlenen yük veya deplasman metodlarıyla tasarlanmaktadır. Tasarım amacına dair günümüzdeki görüşe gore, güvenilirlik analizi gerekliliklerinin yükleri, yük faktörlerini ve yük kombinasyonlarını istatistiksel yaklaşımla belirlemesini önermektedir. Deprem yükü konusunda en kayda değer belirsizlik farklı şartnamelerine göre olan farklı tasarım yaklaşımlarının kullanımından kaynaklanmaktadır. Farklı tasarım metodları ve şartnameler farklı malzeme miktarı tüketilmesine (beton ve çelik donatı) ve güvenilirlik elde edilmesine neden olabilir. Çoğu köprü deprem tasarımı, yaygın bir şekilde tercih edilen bir yöntem olan tepki spektrum analiz yöntemine dayanmaktadır. Bu çalışmanın amacı, depremsel tasarım güvenilirliği ve yapısal eleman metrajı arasındaki ilişkiyi belirlemektir çünkü bu konuda literatürde sınırlı araştırma vardır. Bu kapsamda, yüz altmış iki adet farklı köprü altı farklı deprem koşulu altında SAP2000 sonlu elemanlar programı kullanılarak analiz edilmiştir. Detaylı tasarım hesaplamaları kolonlar için yapılmıştır.

Anahtar Kelimeler: Tepki Spektrum Analizi, Deprem Bölgesi, Metraj Hesapları, Güvenilirlik

To My Family and Husband

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I would also appreciate assisting of my mother İffet, my father Sefa who has encouraged me about being a civil engineer, my husband Eser and my sister Bengi in the way of the study.

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CHAPTER 1

INTRODUCTION AND LITERATURE

1.1. General View

1.1.1. Introduction

Highway bridges are generally designed using a modified version of American Association of State Highway and Transportation Officials Standard Specifications for Highway Bridges AASHTO LFD and “Load and Resistance Factor Design” LRFD in Turkey. In development of bridge specifications, allowable stress design has been adopted for many years. Allowable stress design compares the allowable capacity to demand using certain factor of safeties based on engineering judgement. The load factor design (LFD) has been used in later years based on load carrying capacity of members. This design approach uses deterministic methods. The latest design method load resistance factor design (LRFD) is more based on statistical approach accounting for uncertainties.

1.1.2. Literature

Since reliability based evaluations, pushover analysis and seismic design of structural proportions of highway bridges are commonly used; there are many researches about these subjects.

A study about seismic evaluation of the parts of bridges and buildings has been performed with pushover analysis. When a structure faces with a nondestructive ground motion, the capacity of that structure could be evaluated by means of pushover analysis method. In addition, this method also helps to see the picture of damage state in order to determine the retrofitting technique. (Bakshi & Chakravorty, 2010)

The evaluation of pushover analysis procedures for frame structures has been investigated in a study (Oğuz, 2005). The study shows that only the elastic first mode is used to determine the force-displacement curve for a single degree of freedom system (SDOF) which leads to ignorance of the effects of inelasticity, higher modes on the target displacement. Thus, the author suggests that in order to have more accurate result, structural properties and ground motion characteristics need to be taken as near to the exact.

Since considering the design life of a bridge and economy at the same time is an important issue, there is another study prepared about this phenomenon. (Bhattacharya, 2015) The failure reasons which are basically earthquake, tidal waves, scouring, and barge impact have been investigated. Loads have been obtained and collected. Besides, the target safeties, uncertainties, boundary conditions, accuracy of finite element model and cost have been determined.

In many countries, seismic design is not commonly used for bridges having span length less than 50 m and located in moderate or low seismic zone. However, there is a research performed in Budapest Hungary for these types of bridges due to the importance of seismic performance and vulnerability of conventional highway bridges in these bridges. According to the study, slab and multi-girder bridges with elastomeric bearings are worse than multi-girder bridges with monolithic joints with regard to performance against earthquake. In this study, 30 non-seismically located highway bridges are compiled based on the bridge inventory of Hungary. The bridges are selected to represent the typical structures in moderate seismic zones.
(Simon & Vigh, 2017)

Probability of failure or reliability could also be used for bridge management and feasibility. (Lark & Flaig, 2005) The structural adequacy of bridges and the repairing and strengthening part of the structure could be determined by means of reliability analysis. The reliability of an element of a bridge can be used as a part of the bridge management process in various ways. For example, this reliability can be compared with the average acceptable reliability for the bridge type and failure mode under consideration. If the calculated value is below the lower limit of the variability range of the average acceptable value it is reasonable to conclude that the structure is less safe than might be expected of a structure designed in accordance with the codes of practice for that bridge stock.

Risk or reliability analysis could be performed as a parametric study of various bridges or a specifically designed bridge. To illustrate, a study has been for the bridge constructions in Pakistan. The aim of this study is ensuring awareness of the failure of various bridges globally and in Pakistan, and addressing the threats affecting the performance in the construction process of a bridge project, they are likely to face. (Choudhry & Aslam, 2014)

A paper discussed a new sensitivity investigation method of reliability of Systems with Complex Interconnections (SwCI) elaborated. The possibility of use was demonstrated to investigate the SwCI sensitivity by a simple BSS example. SwCIs sensivity model could be established by means of demonstrated mathematical connections and procedure. In brief, this model could be used to investigate system reliability and dependability in a wide context. The study of methodologies of complex system uncertainty have been determined by the Author using other mathematical tools, for example linear interval equations, Monte-Carlo Simulation on basis of proposed reliability sensitivity models (Pokorádi, 2015)

Reliability of the columns could be assessed from the aspect of vehicle impact. The probability of failure during a vehicle impact has been estimated in a study. In this research, the probabilistic and deterministic analyses have been performed. In the result, the deterministic modeling of vehicle modeling is found to be underestimating forces on columns during impact. (Mestrovic, Cizmar, & Miculinic, 2008)

The reliability index theory has been investigated for bridges (Thoft-Christensen & Nowak, 1997). The girder bridge types including non-composite steel, composite steel, reinforced concrete and pre-stressed concrete girders have been assessed to see the reliability. During the process of analysis, both ultimate limit states (ULS) and serviceability limit states (SLS) have been defined. Fınally, the reliability indexes are differing highly.

Bridges have been exposed to uncertainties such as predicting the load-carrying capacity of a structure, the intensities of the extreme events expected to be occurred during service life of the structure, the frequency of these loading events, and the prediction of the effects of these events on the structure. (Michel Ghosn, 2003)

Reliability analysis of existing structures could also be performed in order to see the reliability of transportation networks in U.S. West Coast Bridges in case of hazard. Hazard resilience can be modeled by considering the reliability of the network against disconnection or blocked network flow. Still, a major challenge associated with such analysis is making sure that the component models are realistic while keeping the analysis accurate. Therefore, a methodology has been developed for realistic bridge network modeling. (Kurtz, Junho Song, & Paolo Gardoni, 2016)

Highway bridge columns are designed under static and dynamic load effects. Although seismic loads govern in this study, reliabilities of columns under live loads are summarized in the following figure (Çelik, 2018):

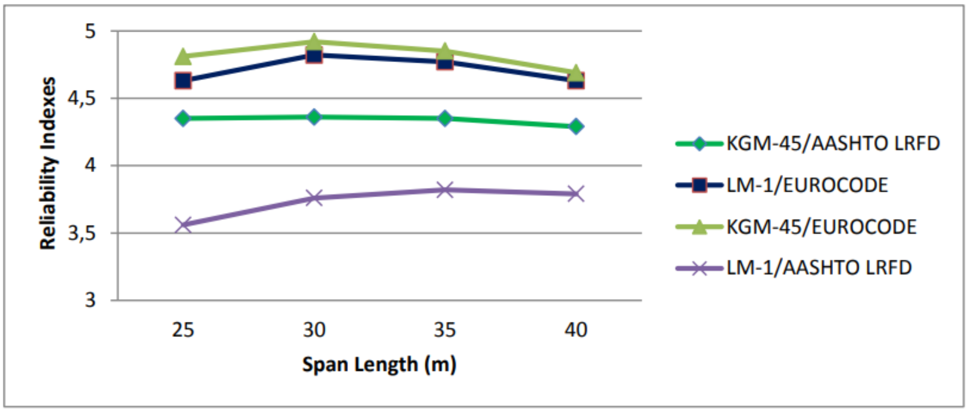


Figure 1.1. Reliability Index versus Span Length for Different Live Load Models and Design Codes

In another study, failure probability of abutments subjected to earthquake loads with regard to sliding, overturning and bearing capacity of soil below foundation has been investigated. The backfill behind the wall and soil under foundation has been considered as random variables. (Basha & Babu, 2010)

A case study about the bridges located in highly seismic region has been performed in order to see the multihazard reliability-based evaluation of RC bridges under combined effects of pier scour and earthquake phenomena. Then the results have been compared with the provisions of specifications in terms of load-modification factors. (Azadeh Alipour, Behrouz Shafei, & Masanobu Shinozuka, 2013)

Reliability based evaluation of seismic design in bridges preferred in Turkey has also been researched which is more related with this study. According to the study of (Yılmaz, 2014) reliability analysis has been performed with choosing random variables as normally distributed except ground accelerations. The results have been mainly assessed for axial force-biaxial bending failure mode during a seismic event. (Yılmaz, 2014) has quantified bending moment reliability analysis for different response modification factors as shown in the following two figures:

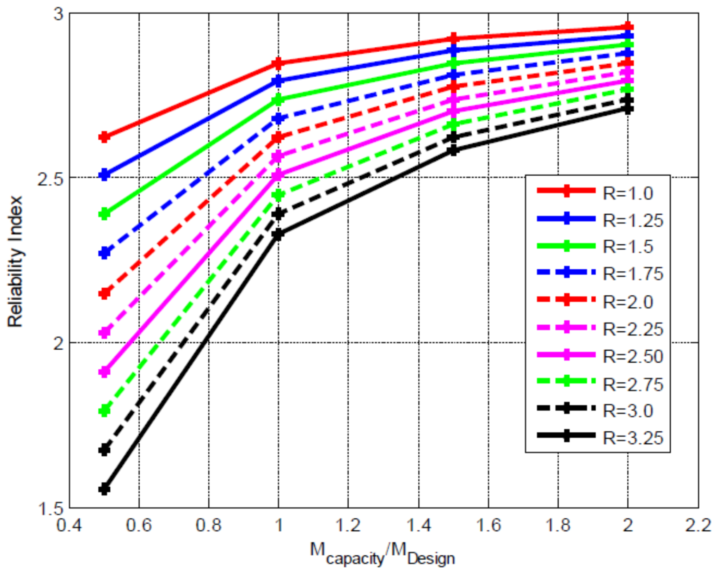


Figure 1.2. Effect of Response Modification Factor on Reliability Index of Biaxial Bending of Pier Columns Designed with using AASHTO LRFD, 2010 together with 1000 Years Return Period PGA

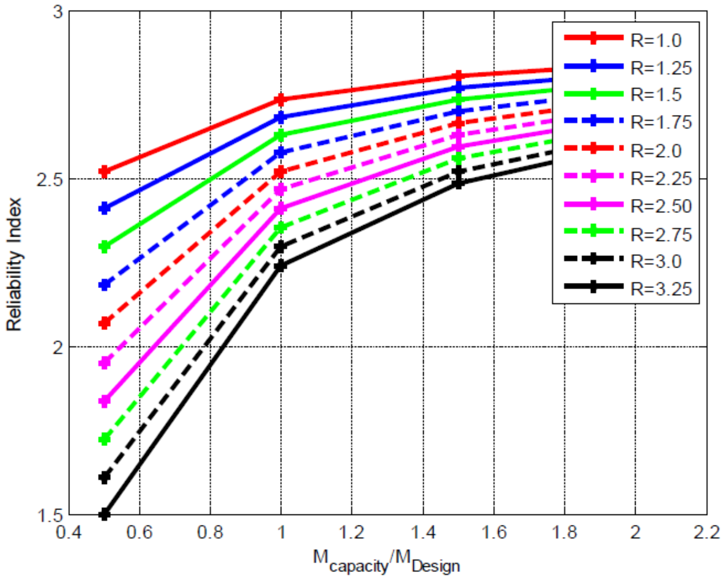


Figure 1.3. Effect of Response Modification Factor on Reliability Index of Biaxial Bending of Pier Columns Designed with using Proposed Design Spectrum together with 475 Years Return Period PGA Values Obtained from Gülkan et al. (1993)

1.2. Aim of the study

Earthquake analysis and design has natural randomness and contains uncertainty that can be quantified thru probabilistic studies. As a result, the design quantity estimation of materials needs to be determined using probabilistic approach.

In the literature, a limited research on reliability analysis of bridge design is available. The focus of the study is given to identify the reliability of bridge column designs with inclusion of quantity estimation thru a large set of parametric analysis based on AASHTO LFD and LRFD design approach. The increase of quantities may not be a guarantee of increase in reliability.

1.3. Scope

Reliability based evaluation have been utilized in highway bridges design for many years A similar approach has been utilized in this study. In this study, one hundred and sixty- two different bridges with precast pre-stressed I girders have been designed. These bridges differ from each other in deck width, clear span length, column height, skewness and number of spans. Bridge models have been prepared for dynamic analysis with different return periods of earthquake and soil conditions using response spectrum analysis. Columns are typically designed to have a minimal damage state (essentially elastic performance) for and earthquake event in Turkey.

The bridges have been investigated using data below:

Place: Kocaeli Kartape Arslanbey Mah.

Lattitude : 40.67686 °

Longitude: 30.02628 °

Parametric study data table is listed below:

Table 1.1. *Parametric Study Data Table*

Deck width (m)	**Span length (m)**	**Skewness (°)**	**Span number**	**Column height (m)**
13	20	0	2	10
20	30	20	3	20
	40	40	4	30

Total analysis number= 2 deck width x 3 span length x 3 skewness x 3 span number x 3 column height = 162

These 162 analyses have been performed in different return period and soil conditions based on AASHTO LFD and LRFD provisions.

Per AASHTO LFD, seismic design loads are set based on an earthquake event with 10% probability of exceedance in 50 years where as in LRFD this probability will be equal to 5% in the same return period. Such an event corresponds to a return period of approximately 475 years and 1000 years respectively.

In summary;

a) According to AASHTO LFD (475 years period, earthquake in 1st degree, soil type I and III)

b) According to AASHTO LRFD and new spectrum values (475 years period + 1000 years period, 30 km far away from fault line, soil type ZB and ZD)

Response spectrum data has been gathered using web1; (Türkiye Deprem Tehlike Haritaları İnteraktif Web Uygulaması, 2019).The web site does not document the 1000 year return period earthquake and an interpolation technique has been applied to compute this particular value utilizing the below earthquake levels.

- ⇨ DD1: 2475 years period,
- ⇨ DD2: 475 years period
- ⇨ DD3: 72 years period,
- ⇨ DD4: 43 years period

Used in interpolation

Organization of the study is summarized in the chart below:

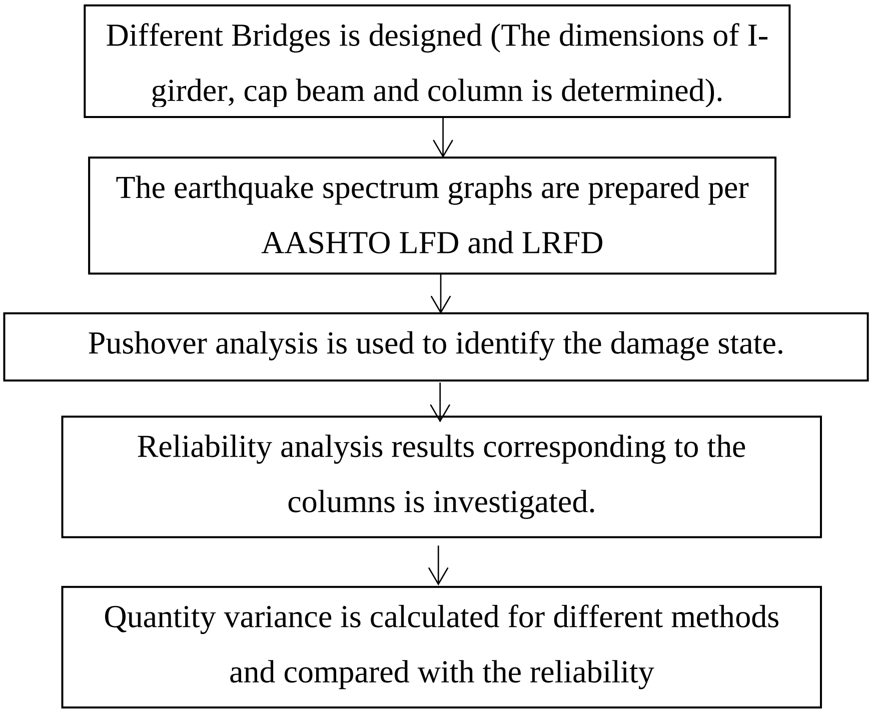


Figure 1.4. Organization of the Study

The details of design and results are given in Appendix.

CHAPTER 2

DESCIPTION AND MODELING OF BRIDGES

The parametric study includes investigation of different bridges for deck width, span length, column height, skewness and number of spans. One hundred sixty two models were generated using the following number of parameters:

- Deck width (m) : 13, 20
- Span length (m) : 20, 30, 40
- Column height (m) : 10, 20, 30
- Skewness (°) : 0, 20, 40
- Number of Spans : 2, 3, 4

Dimensions and the typical section types of structural proportions of one hundred sixty two bridges are given in the table below (The listed abbreviations “ST”, “CT”, “CBT” and “PWP” are superstructure type, column type, cap beam type and plan view of the pier respectively.):

Table 2.1. *Dimensions for One Hundred and Sixty Two Different Bridges*

Analysis Number	Deck Width (m)	Span Length (m)	Column Height (m)	Skewness (°)	Number of Span	ST	CT	CBT	PWP
001	13	20	10	0	2	U1	C1	B1	P1
002	13	20	10	0	3	U1	C1	B1	P1
003	13	20	10	0	4	U1	C1	B1	P1
004	13	20	10	20	2	U1	C2	B2	P2
005	13	20	10	20	3	U1	C2	B2	P2
006	13	20	10	20	4	U1	C2	B2	P2
007	13	20	10	40	2	U1	C1	B2	P3
008	13	20	10	40	3	U1	C1	B2	P3
009	13	20	10	40	4	U1	C1	B2	P3
010	13	20	20	0	2	U1	C3	B1	P4
011	13	20	20	0	3	U1	C3	B1	P4
012	13	20	20	0	4	U1	C3	B1	P4
013	13	20	20	20	2	U1	C3	B2	P5

Table 2.1. *Continued*

Analysis Number	Deck Width (m)	Span Length (m)	Column Height (m)	Skewness (°)	Number of Span	ST	CT	CBT	PWP
014	13	20	20	20	3	U1	C3	B2	P5
015	13	20	20	20	4	U1	C3	B2	P5
016	13	20	20	40	2	U1	C3	B2	P6
017	13	20	20	40	3	U1	C3	B2	P6
018	13	20	20	40	4	U1	C3	B2	P6
019	13	20	30	0	2	U1	C4	B3	P7
020	13	20	30	0	3	U1	C4	B3	P7
021	13	20	30	0	4	U1	C4	B3	P7
022	13	20	30	20	2	U1	C4	B3	P8
023	13	20	30	20	3	U1	C4	B3	P8
024	13	20	30	20	4	U1	C4	B3	P8
025	13	20	30	40	2	U1	C5	B3	P9
026	13	20	30	40	3	U1	C5	B3	P9
027	13	20	30	40	4	U1	C5	B3	P9
028	13	30	10	0	2	U2	C1,C3	B1	P1
029	13	30	10	0	3	U2	C1,C3	B1	P1
030	13	30	10	0	4	U2	C1,C3	B1	P1
031	13	30	10	20	2	U2	C2,C6	B2	P2
032	13	30	10	20	3	U2	C2,C6	B2	P2
033	13	30	10	20	4	U2	C2,C6	B2	P2
034	13	30	10	40	2	U2	C1	B2	P3
035	13	30	10	40	3	U2	C1	B2	P3
036	13	30	10	40	4	U2	C1	B2	P3
037	13	30	20	0	2	U2	C3	B1	P4
038	13	30	20	0	3	U2	C3	B1	P4
039	13	30	20	0	4	U2	C3	B1	P4
040	13	30	20	20	2	U2	C3	B2	P5
041	13	30	20	20	3	U2	C3	B2	P5
042	13	30	20	20	4	U2	C3	B2	P5
043	13	30	20	40	2	U2	C3	B2	P6
044	13	30	20	40	3	U2	C3	B2	P6
045	13	30	20	40	4	U2	C3	B2	P6
046	13	30	30	0	2	U2	C4	B3	P7
047	13	30	30	0	3	U2	C4	B3	P7
048	13	30	30	0	4	U2	C4	B3	P7
049	13	30	30	20	2	U2	C4	B3	P8
050	13	30	30	20	3	U2	C4	B3	P8
051	13	30	30	20	4	U2	C4	B3	P8
052	13	30	30	40	2	U2	C5	B3	P9
053	13	30	30	40	3	U2	C5	B3	P9
054	13	30	30	40	4	U2	C5	B3	P9
055	13	40	10	0	2	U3	C3,C10	B4	P10
056	13	40	10	0	3	U3	C3,C10	B4	P10
057	13	40	10	0	4	U3	C3,C10	B4	P10
058	13	40	10	20	2	U3	C6,C11	B4	P11
059	13	40	10	20	3	U3	C6,C11	B4	P11

Table 2.1. *Continued*

Analysis Number	Deck Width (m)	Span Length (m)	Column Height (m)	Skewness (°)	Number of Span	ST	CT	CBT	PWP
060	13	40	10	20	4	U3	C6,C11	B4	P11
061	13	40	10	40	2	U3	C3	B4	P12
062	13	40	10	40	3	U3	C3	B4	P12
063	13	40	10	40	4	U3	C3	B4	P12
064	13	40	20	0	2	U3	C6	B4	P13
065	13	40	20	0	3	U3	C6	B4	P13
066	13	40	20	0	4	U3	C6,C11	B4	P13
067	13	40	20	20	2	U3	C7,C11	B4	P14
068	13	40	20	20	3	U3	C7,C11	B4	P14
069	13	40	20	20	4	U3	C7,C11	B4	P14
070	13	40	20	40	2	U3	C3,C10	B4	P12
071	13	40	20	40	3	U3	C3,C10	B4	P12
072	13	40	20	40	4	U3	C3,C10	B4	P12
073	13	40	30	0	2	U3	C8	B5	P15
074	13	40	30	0	3	U3	C8	B5	P15
075	13	40	30	0	4	U3	C8	B5	P15
076	13	40	30	20	2	U3	C8	B5	P16
077	13	40	30	20	3	U3	C8	B5	P16
078	13	40	30	20	4	U3	C8	B5	P16
079	13	40	30	40	2	U3	C9	B5	P17
080	13	40	30	40	3	U3	C9	B5	P17
081	13	40	30	40	4	U3	C9	B5	P17
082	20	20	10	0	2	U4	C6	B3	P18
083	20	20	10	0	3	U4	C6	B3	P18
084	20	20	10	0	4	U4	C6	B3	P18
085	20	20	10	20	2	U4	C7	B3	P19
086	20	20	10	20	3	U4	C7	B3	P19
087	20	20	10	20	4	U4	C7	B3	P19
088	20	20	10	40	2	U4	C6	B3	P20
089	20	20	10	40	3	U4	C6	B3	P20
090	20	20	10	40	4	U4	C6	B3	P20
091	20	20	20	0	2	U4	C10	B3	P21
092	20	20	20	0	3	U4	C10	B3	P21
093	20	20	20	0	4	U4	C10	B3	P21
094	20	20	20	20	2	U4	C11	B3	P22
095	20	20	20	20	3	U4	C11	B3	P22
096	20	20	20	20	4	U4	C11	B3	P22
097	20	20	20	40	2	U4	C10	B3	P23
098	20	20	20	40	3	U4	C10	B3	P23
099	20	20	20	40	4	U4	C10	B3	P23
100	20	20	30	0	2	U4	C12	B5	P24
101	20	20	30	0	3	U4	C12	B5	P24
102	20	20	30	0	4	U4	C12	B5	P24
103	20	20	30	20	2	U4	C12	B5	P25
104	20	20	30	20	3	U4	C12	B5	P25
105	20	20	30	20	4	U4	C12	B5	P25

Table 2.1. *Continued*

Analysis Number	Deck Width (m)	Span Length (m)	Column Height (m)	Skewness (°)	Number of Span	ST	CT	CBT	PWP
106	20	20	30	40	2	U4	C13	B5	P26
107	20	20	30	40	3	U4	C13	B5	P26
108	20	20	30	40	4	U4	C13	B5	P26
109	20	30	10	0	2	U5	C11	B6	P27
110	20	30	10	0	3	U5	C11	B6	P27
111	20	30	10	0	4	U5	C11	B6	P27
112	20	30	10	20	2	U5	C14	B6	P28
113	20	30	10	20	3	U5	C14	B6	P28
114	20	30	10	20	4	U5	C14	B6	P28
115	20	30	10	40	2	U5	C11	B6	P29
116	20	30	10	40	3	U5	C11	B6	P29
117	20	30	10	40	4	U5	C11	B6	P29
118	20	30	20	0	2	U5	C15	B6	P30
119	20	30	20	0	3	U5	C15	B6	P30
120	20	30	20	0	4	U5	C15	B6	P30
121	20	30	20	20	2	U5	C16	B6	P31
122	20	30	20	20	3	U5	C16	B6	P31
123	20	30	20	20	4	U5	C16	B6	P31
124	20	30	20	40	2	U5	C15	B6	P32
125	20	30	20	40	3	U5	C15	B6	P32
126	20	30	20	40	4	U5	C15	B6	P32
127	20	30	30	0	2	U5	C17	B7	P33
128	20	30	30	0	3	U5	C17	B7	P33
129	20	30	30	0	4	U5	C17	B7	P33
130	20	30	30	20	2	U5	C17	B7	P34
131	20	30	30	20	3	U5	C17	B7	P34
132	20	30	30	20	4	U5	C17	B7	P34
133	20	30	30	40	2	U5	C18	B7	P35
134	20	30	30	40	3	U5	C18	B7	P35
135	20	30	30	40	4	U5	C18	B7	P35
136	20	40	10	0	2	U6	C19	P8	P36
137	20	40	10	0	3	U6	C19	P8	P36
138	20	40	10	0	4	U6	C19	P8	P36
139	20	40	10	20	2	U6	C20	P8	P37
140	20	40	10	20	3	U6	C20	P8	P37
141	20	40	10	20	4	U6	C20	P8	P37
142	20	40	10	40	2	U6	C19	P8	P38
143	20	40	10	40	3	U6	C19	P8	P38
144	20	40	10	40	4	U6	C19	P8	P38
145	20	40	20	0	2	U6	C21	P8	P39
146	20	40	20	0	3	U6	C21	P8	P39
147	20	40	20	0	4	U6	C21	P8	P39
148	20	40	20	20	2	U6	C22	P8	P40
149	20	40	20	20	3	U6	C22	P8	P40
150	20	40	20	20	4	U6	C22	P8	P40
151	20	40	20	40	2	U6	C21	P8	P41

Table 2.1. *Continued*

Analysis Number	Deck Width (m)	Span Length (m)	Column Height (m)	Skewness (°)	Number of Span	ST	CT	CBT	PWP
152	20	40	20	40	3	U6	C21	P8	P41
153	20	40	20	40	4	U6	C21	P8	P41
154	20	40	30	0	2	U6	C23	P9	P42
155	20	40	30	0	3	U6	C23	P9	P42
156	20	40	30	0	4	U6	C23	P9	P42
157	20	40	30	20	2	U6	C23	P9	P43
158	10	10	10	10	10	10	10	10	10
159	10	10	10	10	10	10	10	10	10
160	10	10	10	10	10	10	10	10	10
161	10	10	10	10	10	10	10	10	10
162	10	10	10	10	10	10	10	10	10

SAP 2000 software has been used to model these bridges. A typical model has been shown in the following figure:

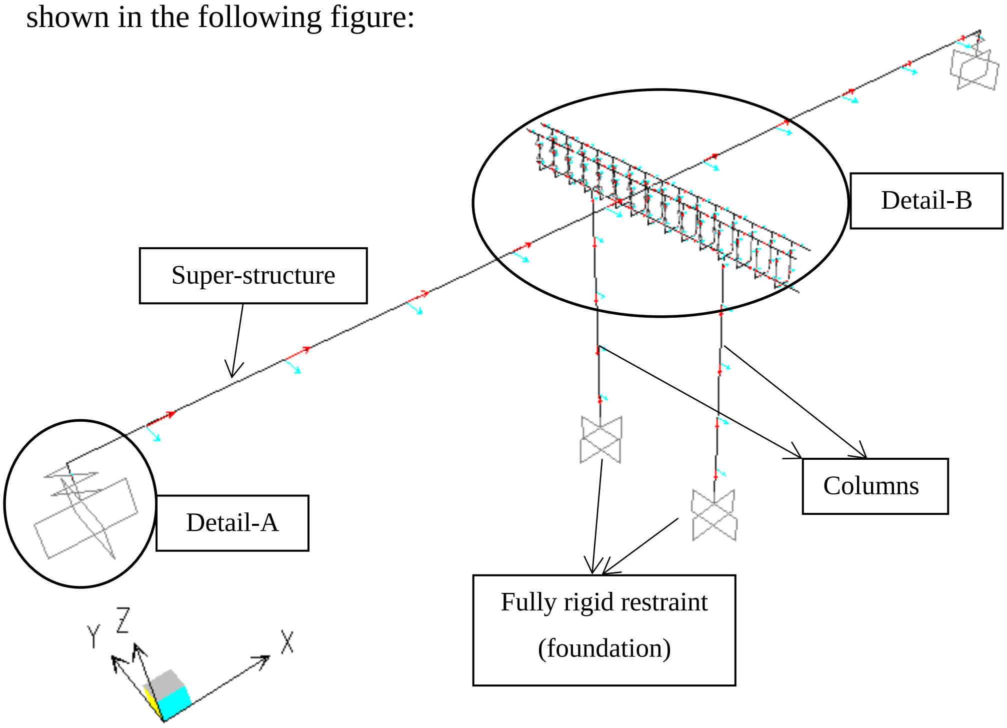


Figure 2.1. General View of the Model

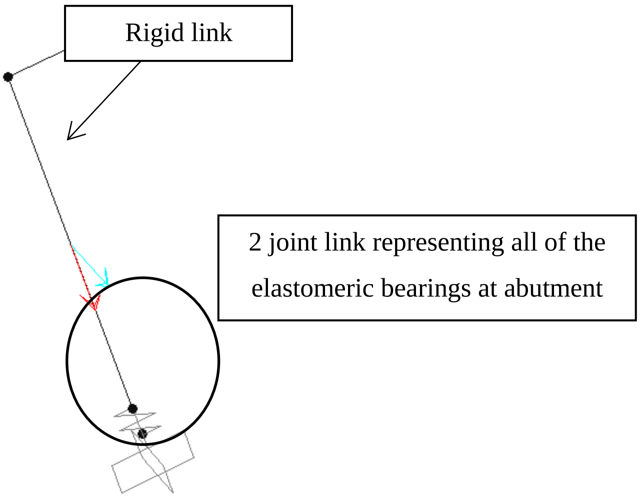


Figure 2.2. Detail "A" Shown in the Figure 2.1.

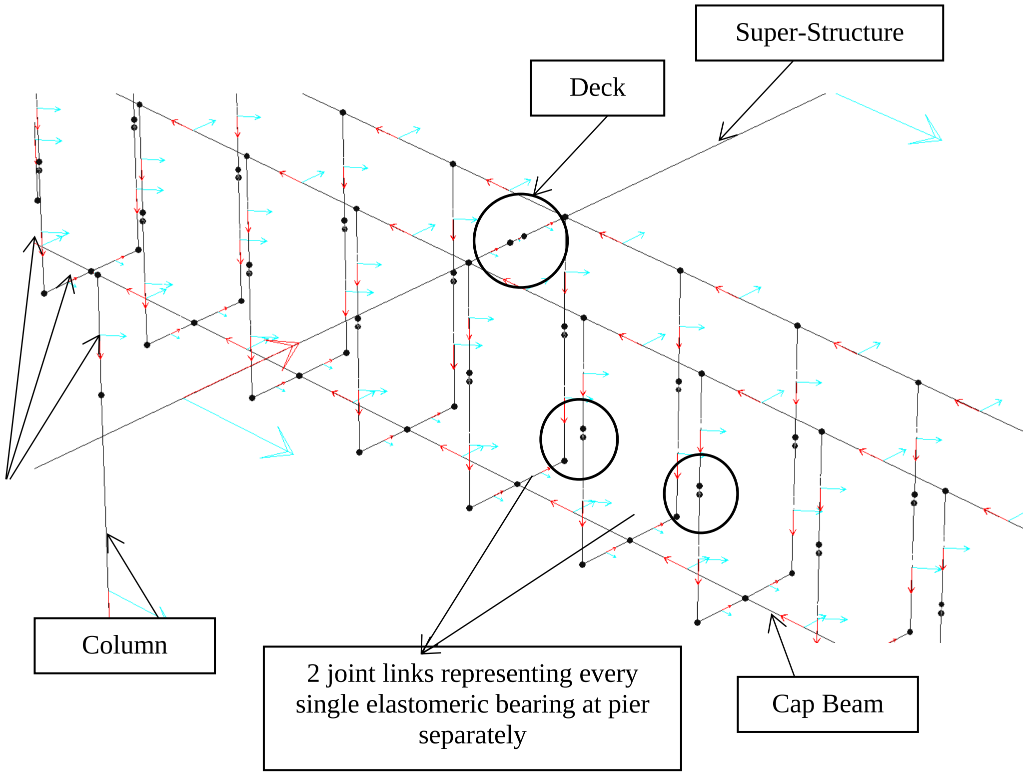


Figure 2.3. Detail "B" Shown in the Figure 2.1.

Superstructure mass and stiffness have been modeled with a single equivalent beam element. The beam element material and section properties have been given to

SAP2000 model. At the sections of beams are separated from each other, superstructure parts have been bound with the elements defined with the properties of deck. The area and inertia of deck is much softer than the superstructures.

As it has been known, the typical superstructure consists of multiple girders on slab. General cross-sectional view of a superstructure is represented in the figure below:

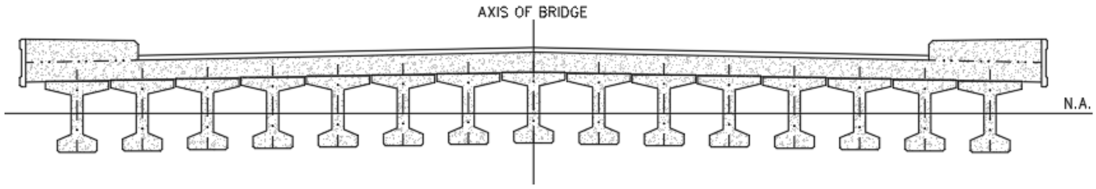


Figure 2.4. Typical Superstructure Cross-Sectional View

The equivalent mass and stiffness have been computed around the neutral axis of the superstructure. Each span has been divided to a number of segments to have a better distribution of mass along the span length. Typical superstructure profile is represented below to show the rigid link location of usage:

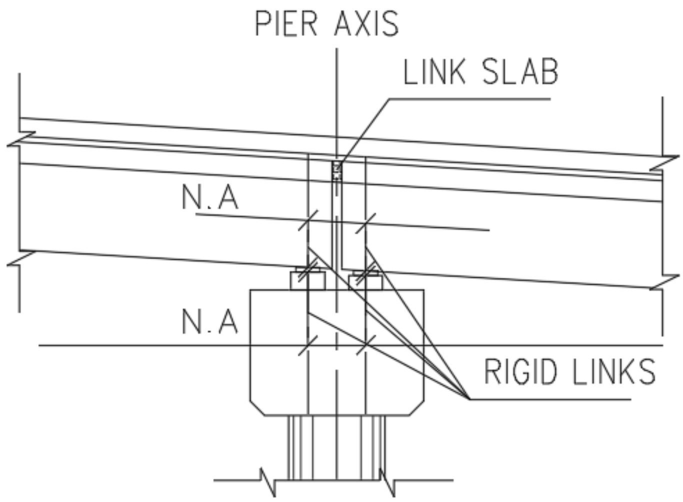


Figure 2.5. Typical Superstructure Profile View

Superstructure design is based on typical engineering practice in Turkey. As span length increases, the girder depth increases as well. The general span to depth ratio varies between 22 and 25. Used parameters are shown below:

Table 2.2. *Parameters of Superstructure*

Span Length (m)	Deck Width (m)	Girder Depth (m)	Span Length / Girder Depth
20	13	0.9	22
30	13	1.2	25
40	13	1.8	22
20	20	0.9	22
30	20	1.2	25
40	20	1.8	22

Drawings of the superstructure types and pier layout plans are shown in the figures in Appendix A in detail. Besides, the pier layout plans, the representative figures of S1, S2 and S3 dimensions and their numerical values are simply shown in the figures and table below:

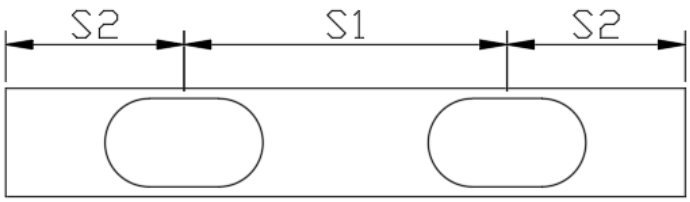


Figure 2.6. Pier Layout Geometry Type 1

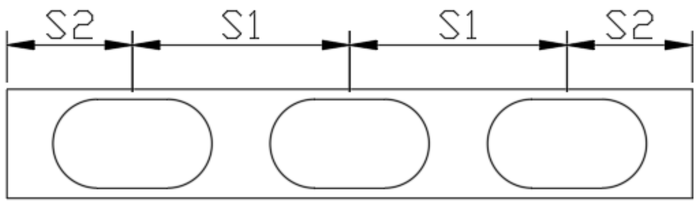


Figure 2.7. Pier Layout Geometry Type 2

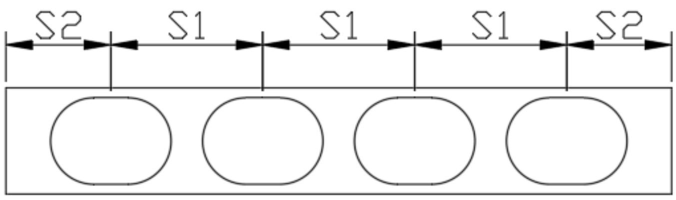


Figure 2.8. Pier Layout Geometry Type 3

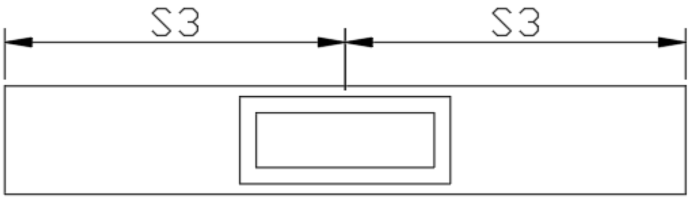


Figure 2.9. Pier Layout Geometry Type 4

Table 2.3. *Pier Layout Plan Geometry and Dimensions*

PIER LAYOUT TYPE	GEOMETRY TYPE	S_1(m)	S_2(m)	S_3(m)
P1	TYPE 1	6.500	3.250	-
P2	TYPE 1	7.000	3.417	-
P3	TYPE 2	5.750	2.735	-
P4	TYPE 1	6.500	3.250	-
P5	TYPE 1	7.000	3.417	-
P6	TYPE 2	5.750	2.735	-
P7	TYPE 4	-	-	6.500
P8	TYPE 4	-	-	6.917
P9	TYPE 4	-	-	8.485
P10	TYPE 1	6.500	3.250	-
P11	TYPE 1	7.000	3.417	-
P12	TYPE 2	5.750	2.735	-
P13	TYPE 1	6.500	3.250	-
P14	TYPE 1	7.000	3.417	-
P15	TYPE 4	-	-	6.500
P16	TYPE 4	-	-	6.917
P17	TYPE 4	-	-	8.485
P18	TYPE 2	6.750	3.250	-
P19	TYPE 2	7.250	3.392	-
P20	TYPE 3	6.500	3.304	-
P21	TYPE 2	6.750	3.250	-
P22	TYPE 2	7.250	3.392	-
P23	TYPE 3	6.500	3.304	-
P24	TYPE 4	-	-	10.000
P25	TYPE 4	-	-	10.642
P26	TYPE 4	-	-	13.054
P27	TYPE 2	6.750	3.250	-
P28	TYPE 2	7.250	3.392	-
P29	TYPE 3	6.500	3.304	-
P30	TYPE 2	6.750	3.250	-
P31	TYPE 2	7.250	3.392	-
P32	TYPE 3	6.500	3.304	-
P33	TYPE 4	-	-	10.000
P34	TYPE 4	-	-	10.642

Table 2.*3. Continued*

PIER LAYOUT TYPE	GEOMETRY TYPE	S_1(m)	S_2(m)	S_3(m)
P35	TYPE 4	-	-	13.054
P36	TYPE 1	10.000	5.000	-
P37	TYPE 1	11.000	5.142	-
P38	TYPE 2	8.750	4.304	-
P39	TYPE 1	10.000	5.000	-
P40	TYPE 1	11.000	5.142	-
P41	TYPE 2	8.750	4.304	-
P42	TYPE 4	-	-	10.000
P43	TYPE 4	-	-	10.642
P44	TYPE 4	-	-	13.054

Material and sectional properties of cap beam, column and deck have been given to the software. Elastomeric bearings are represented with two joint links as shown in the figures 2.2 and 2.3. They are at different level than neutral axis of superstructure. The offset has been modeled with rigid links. For each model, bearings have been designed for the analyzed loads. Over piers, each bearing have been modeled individually whereas over abutments, lump sum stiffness has been produced to simulate the group stiffness of bearings.

The horizontal bearing stiffness in the longitudinal and lateral direction of bridge has been determined from the following equation:

At the piers (separate links having the properties of each):

In the longitudinal direction of bridge, $K_{x,s}= \frac{LxBxG}{h_{net}}$ (2.1)

Where,

L :horizontal dimension of bearing in the related direction (mm)

B :horizontal dimension of bearing perpendicular to the related direction (mm)

G :shear modulus of rubber, 100 t/m^2

h_{net} :net thickness of elastomeric bearing (thickness without the steel layer) (mm)

In the lateral direction of bridge, $K_{y,s}= 10 \times K_{x,s}$ (2.2)

In the vertical direction of bridge, $K_{v,s}=\frac{LxBxE}{h_{net}}$ (2.3)

Rotational rigidity has been ignored.

Where,

E :elastic modulus of bearing

At the abutments (one link having the properties of all):

In the longitudinal direction of bridge, $K_{x,a}= K_{x,s} \times n$ (2.4)

In the lateral direction of bridge, $K_{y,a}= 10 \times K_{x,a}$ (2.5)

In the vertical direction of bridge, $K_{v,a}=K_{y,s} \times n$ (2.6)

n : number of elastomeric bearings in one axis

Rotational rigidity in the vertical direction of bridge: $\Sigma K_{x,s,i} \times \Sigma X_i^2$ (2.7)

Where,

X_i :horizontal distance of each bearing to horizontal axis of bridge

Rotational rigidity in the longitudinal direction of bridge: $\Sigma K_{v,i} \times \Sigma X_i^2$ (2.8)

Cap beam has been modelled to have its own stiffness and mass based on uncracked sectional properties. The offset from bottom of bearings and neutral axis of cap beam has been modelled with rigid links. Cap beams are modelled with a rectangular shape and the dimension representation is shown below:

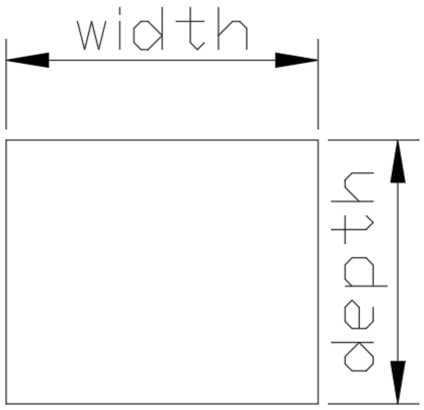


Figure 2.10. Cap Beam Dimension Representation

Cap beam dimensions are determined mainly based on skewness and deck width of bridge. Selected dimensions are summarized in the table below:

Table 2.4. *Cap Beam Dimensions*

Cap Beam	Depth (m)	Width (m)
B1	1.5	2
B2	1.7	2.2
B3	2	3
B4	2	2.5
B5	2.5	4
B6	2.5	3.5
B7	2	4.5
B8	3	4
B9	3.5	5

Cap beam depth has been change from 1.5m to 3.5m. The increase in deck width and skewness can result in higher depth for cap beam. Width of the cap beam varied from 2m to 5m for the same reason. There is no simple trend for selection of cap beam and either geometric requirements or loads yields the selection of cap beam dimension.

Columns have been modeled using cracked section properties having $0.5 \times I_{gross}$ where I_{gross} is the gross moment of inertia of column. The area and torsional rigidity has been taken as gross. The column dimensions are represented in the figure and given in detail in the table below:

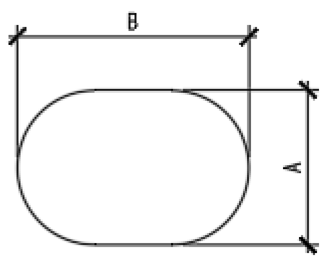


Figure 2.11. Elliptical Shape Column Dimension Representation

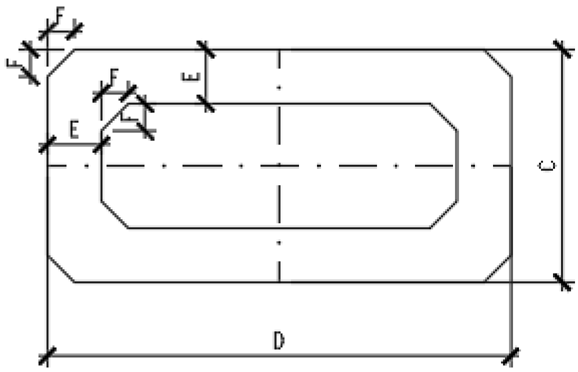


Figure 2.12. Box Shape Column Dimension Representation

Table 2.5. *Column Types and Dimensions*

Column Type	Shape	Number of Cell	Dimensions (m)					
			A	B	C	D	E	F
C1	elliptic	-	1.5	2.5	-	-	-	-
C2	elliptic	-	1.5	3	-	-	-	-
C3	elliptic	-	2	3	-	-	-	-
C4	box	one	-	-	3	6	0.7	0.35
C5	box	one	-	-	3	7	0.7	0.35
C6	elliptic	-	2	3.5	-	-	-	-
C7	elliptic	-	2	4	-	-	-	-
C8	box	one	-	-	4	7	0.8	0.5
C9	box	one	-	-	4	8	0.8	0.5
C10	elliptic	-	2.5	3.5	-	-	-	-
C11	elliptic	-	2.5	4	-	-	-	-
C12	box	two	-	-	4	10	0.8	0.5
C13	box	two	-	-	4	14	0.8	0.5
C14	elliptic	-	2.5	4.5	-	-	-	-
C15	elliptic	-	3	4	-	-	-	-
C16	elliptic	-	3	4.5	-	-	-	-
C17	box	two	-	-	4.5	10	1	0.5
C18	box	two	-	-	4.5	14	1	0.5
C19	elliptic	-	3	5	-	-	-	-
C20	elliptic	-	3	5.5	-	-	-	-
C21	elliptic	-	3.5	5.5	-	-	-	-
C22	elliptic	-	3.5	6	-	-	-	-
C23	box	two	-	-	5	10	1	0.5
C24	box	two	-	-	5	14	1	0.5

Box section type of columns is usually selected for column height higher than or equal to 30m in Turkey. In this study, the same practice has been utilized.

When the column dimensions have been determined, slenderness has been taken into account.

Slenderness ratio: $\lambda=\frac{k*L}{r}$ (This equation can be taken for the design) (2.9)

Where,

k x L :buckling length of compression member (taken as 2 times clear length of column),

r :radius of gyration, r=$\sqrt{\frac{I}{A}}$,

I :moment of inertia in the regarding direction,

A :cross sectional area

The related calculations of columns are listed in Appendix C.

Slenderness ratio values have been arranged to be less than 100 in order to perform rough methods for second order effect. In other words, the column dimensions are determined according to height of them because slenderness ratio is related with the cross-sectional dimensions and the height of columns.

The moments affecting the columns due to seismic design loads have been diminished with response modification factors given in AASHTO LFD and AASHTO LRFD.

Table 2.6. *Response Modification Factors (AASHTO LRFD, 2010)*

Substructure	Operational Category		
	Critical	Essential	Other
Wall-type piers—larger dimension	1.5	1.5	2.0
Reinforced concrete pile bents			
• Vertical piles only	1.5	2.0	3.0
• With batter piles	1.5	1.5	2.0
Single columns	1.5	2.0	3.0
Steel or composite steel and concrete pile bents			
• Vertical pile only	1.5	3.5	5.0
• With batter piles	1.5	2.0	3.0
Multiple column bents	1.5	3.5	5.0

Table 2.7. *Response Modification Factors (AASHTO LFD, 2002)*

TABLE 3.7 Response Modifications Factor (R)

Substructure[1]	R	Connections[3]	R
Wall- type pier[2]	2	Superstructure to abutment	0.8
Reinforced concrete pile bents		Expansion joints within a	
a. Vertical piles only	3	span of the superstructure	0.8
b. One or more batter piles	2	Columns, piers or pile bents	
Single columns	3	to cap beam or superstructure[4]	1.0
Steel or composite steel		Columns or piers to foundations[4]	1.0
and concrete pile bents			
a. Vertical piles only	5		
b. One or more batter piles	3		
Multiple column bent	5		

[1]The R-Factor is to be used for both orthogonal axes of the substructure.

[2]A wall-type pier may be designed as a column in the weak direction of the pier provided all the provisions for columns in Article 6.6 or 7.6, as appropriate, are followed. The R-Factor for a single column may then be used.

[3]Connections are those mechanical devices which transfer shear and axial forces from one structural component to another. They generally do not include moment connections and thus comprise bearings and shear keys. The R factors in this Table are applied to the elastic forces in the restrained directions only.

[4]For bridges classified as SPC C or D, it is recommended that the connections be designed for the maximum forces capable of being developed by plastic hinging of the column or column bent as specified in Article 7.2.5. These forces will often be significantly less than those obtained using an R-Factor of 1.

Since the type of bridges have been taken as other type, the response modification factor value is the same for AASHTO LFD,2002 and AASHTO LRFD,2010. For the columns acting like wall type, R value has been taken as “2”. For single columns, this value has been taken as “3” while for multiple columns it has been taken as “5”. For multiple columns showing wall type characteristics, this value has been taken as “3.5” which is a value between “2 and 5”.

AASHTO LFD,2002 and AASHTO LRFD,2010 propose to use longitudinal reinforcement with minimum ratio of 1% for the columns resisting to axial loads. However, when the selected column dimensions are larger than required, the reinforcement ratio could be reduced while effective area to be used in calculations are reduced based on AASHTO LFD,2002. The concrete and reinforcement amounts in addition to confinement ratios determined for columns are summarized in the tables listed in Appendix B. If the concrete area and effective area have different values in that tables, then it can be said that there is a reduction of reinforcement below the ratio of 1%.

Materials used in the models are represented below:

Concrete:

- I beam: C45 type having f_c'=45 MPa and E=31730 MPa
  (in Turkish Standards)

- Deck and substructure: C30 type having f_c'=30 MPa and E=25907 MPa
  (in Turkish Standards)

Reinforcement and pre-stressing strand:

- Reinforcement: S420 type having f_y=420 MPa and E=200000 MPa
  (in Turkish Standards)

- Pre-stressing Strand: f_y=1860 MPa and E=197000 MPa
  (in Turkish Standards)

CHAPTER 3

ANALYSIS OF BRIDGES

In seismic evaluation, demands are typically obtained thru elastic methods such as uniform load method, single spectral method or multimode spectral method. For each number of bridges, capacity to demand ratio can be computed using pushover analysis for some defined limit states. Pushover analysis has been also performed to verify the performance of force based design thru displacement based damage states. (Ian Buckle, 2006)

Reliability analysis is usually used to evaluate the safety of design based on statistical data on load occurrences, material uncertainties, construction uncertainties and load intensities. In this study, reliability values are computed based on defined uncertainties in capacity and demand.

3.1. Multiple Spectral Method

For seismic analysis in design is typically based on multimode spectral method per AASHTO LRFD, 2010. For multispan bridges other than multimode spectral method, uniform load elastic method, single mode elastic mode and time history can be applied as well. In this study, multimode spectral method has been selected as the analysis tool since bridges are classified as “other bridges”. The most advance analysis in this class is multimode spectral analysis.

Mass participation in three directions may not develop at the same mode and the cumulative mass distribution close to 90% includes many modes. In this case, a three dimensional analysis is required to represent the structure usually the number of modes shall be at least three times the number of spans. The complete quadratic combination (CQC) has been used to combine the moment, force and displacement for all modes.

Maximum response from all the modes is combined using the following double summation equation. (Wilson, 2014)

$$F=\sqrt{\sum_n \sum_m f_n \rho_{nm} f_m} \quad (3.1.1)$$

Where:

f_n :the modal response of mode n

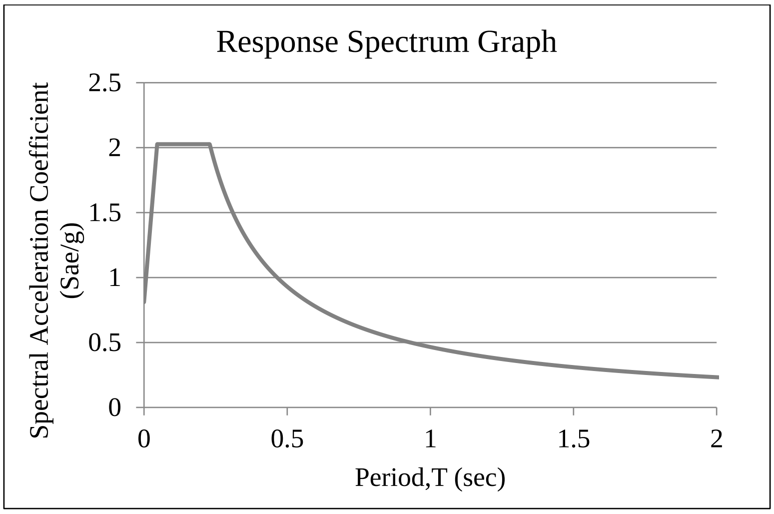
ρ_{nm} :cross modal coefficient = $\frac{8\zeta^2(1+r)r^{3/2}}{(1-r^2)^2+4\zeta^2 r(1+r)^2}$

r :$\omega_n / \omega_m \leq 1.0$

ζ :damping ratio

For each mode, response spectrum shall be used in the analysis.

Response spectrum curve can be developed using the equations given in the web1; (Türkiye Deprem Tehlike Haritaları İnteraktif Web Uygulaması, 2019).



$S_{ae}(T)= (0.4+0.6(T/T_A))S_{DS}$ $\quad 0 \leq T \leq T_A$

$S_{ae}(T)= S_{DS}$ $\quad T_A \leq T \leq T_B$

$S_{ae}(T)= S_{D1}/T$ $\quad T_B \leq T \leq T_L$

$S_{ae}(T)= S_{D1}T_L/T^2$ $\quad T_L \leq T$

$T_A= 0.2S_{D1}/S_{DS}$ $\quad T_B= S_{D1}/S_{DS}$ $\quad T_L= 6s$

Figure 3.1. Response Spectrum Graph Parameters

This method utilizes mainly acceleration spectrum versus period graph in computations and could be developed using the parameters stated in Table 3-1. In this thesis, the bridges have been designed for Kocaeli Kartape where high acceleration values are expected as mentioned before.

Response spectrum graphs have been determined for 475 years return period and 1st earthquake zone with ZI and ZIII soil types using AASHTO LFD 2002 in addition to 475 and 1000 years return period with ZB and ZD soil types using AASHTO LRFD 2010 and web1; (Türkiye Deprem Tehlike Haritaları İnteraktif Web Uygulaması, 2019). Soil type "ZI" is stated as a profile with rock of any characteristic or stiff soil conditions where soil depth is less than 60 meters and the soil types overlying rock are stable deposits of sands, gravels or stiff clays whereas "Z3" is a profile with soft to medium-stiff clays and sands characterized by 9 meters or more of soft to medium clays with or without intervening layers of sand or other cohesionless soils in AASHTO LFD. In AASTO LRFD, these soil types become approximately "ZB" and "ZD" respectively. This spectral curve types have been summarized below:

Type 1	LFD-ZI,
Type 2	LFD-ZIII,
Type 3	LRFD-ZB-475 years period,
Type 4	LRFD-ZD-475 years period,
Type 5	LRFD-ZB-1000 years period,
Type 6	LRFD-ZD-1000 years period,

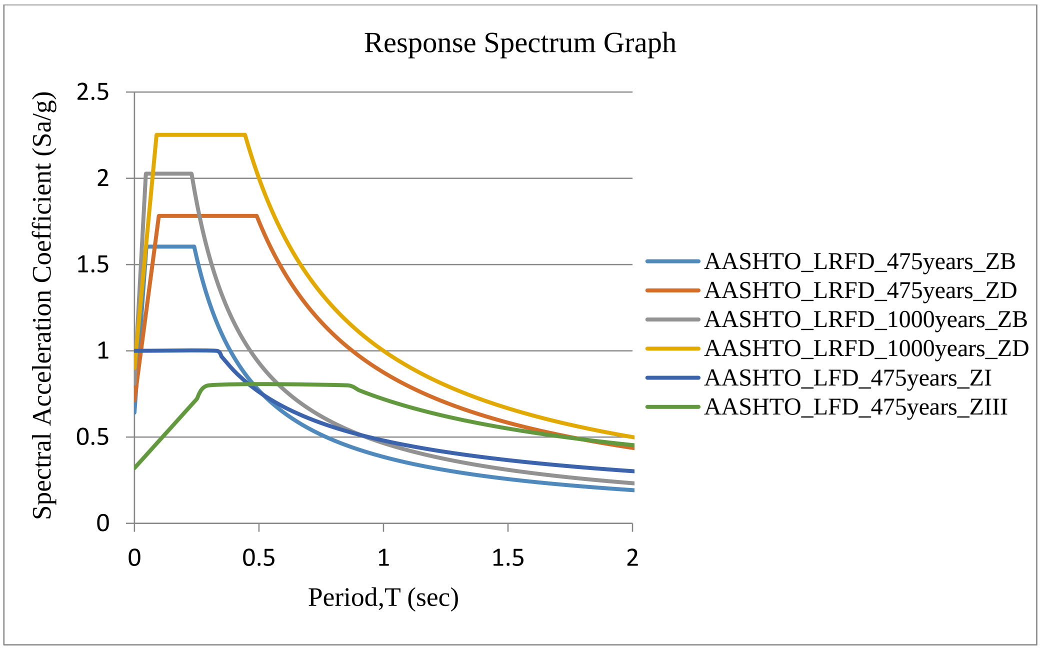


Figure 3.2. Response Spectrum Graph for 6 Different Seismic Cases

Figure 3-2 has been developed using the parameters below:

Table 3.1. *Spectral Parameters*

Soil Type	Yearly Period	1/(Yearly Period)	PGA (g)	S_{DS}	S_{D1}	T_A (sec)	T_B (sec)
ZB	43	0.0233	0.15	0.342	0.081	0.042	0.211
ZB	72	0.0139	0.27	0.626	0.154	0.044	0.219
ZB	475	0.0021	0.726	1.782	0.481	0.048	0.240
ZB	1000	0.0010	0.890	2.252	0.581	0.046	0.230
ZB	2475	0.0004	1.214	3.112	0.876	0.050	0.250
ZD	43	0.0233	0.15	0.342	0.081	0.074	0.372
ZD	72	0.0139	0.27	0.626	0.154	0.087	0.434
ZD	475	0.0021	0.726	1.782	0.481	0.098	0.491
ZD	1000	0.0010	0.890	2.252	0.581	0.089	0.444
ZD	2475	0.0004	1.214	3.112	0.876	0.096	0.479

3.2. Pushover Analysis

Pushover analysis is non-linear static analysis and can be simplified using the methodology given in Seismic Retrofitting Manual for Highway Structures: Part 1- Bridges (Ian Buckle, 2006)

Columns can be designed based on force method and checked by displacement method. Pushover analysis is part of displacement method. This analysis method helps to determine the failure type and elastic and ultimate displacement capacities. In order to reach the results, the table below has been used:

Table 3.2. *Values of Plastic Curvature Corresponding to Various Limit States in Reinforced Concrete Columns and Beams (Ian Buckle, 2006)*

Column or Beam Limit State	**Plastic Curvature, Φ_p[1,2]**
Compression failure, unconfined concrete	$\Phi p = \frac{\varepsilon_{cu}}{c} - \Phi_y$
Compression failure, confined concrete	$\Phi p = \frac{\varepsilon_{cu}}{(c-d'')} - \Phi_y$
Buckling of longitudinal bars	$\Phi p = \frac{\varepsilon_b}{(c-d')} - \Phi_y$
Fracture of longitudinal reinforcement	$\Phi p = \frac{\varepsilon_{s,max}}{(d-c)} - \Phi_y$
Low- cycle fatigue of longitudinal reinforcement	$\Phi p = \frac{2\varepsilon_{ap}}{(d-d')} = \frac{2\varepsilon_{ap}}{D'}$
Lap-splice failure: (a) long / confined lap-splices (b) short / unconfined lap-splices	See low cycle fatigue $\Phi_p = (\mu_{lap\Phi} + 7)\Phi_y$
Shear failure: (a) brittle (b) semi-ductile	$\Phi p = 0$ $\Phi p = (5(\frac{V_m - V_f}{V_i - V_f}) + 2)\Phi_y$
Joint or connection failure: (a) weak joint / strong column (b) semi-ductile	$\Phi p = 0.04$ rad $\Phi p = (4(\frac{V_{jh} - V_{jf}}{V_{ji} - V_{jf}}) + 2)\Phi_y$

The first five cases have been investigated and the other cases have been neglected.

Where:

ε_{cu} :the ultimate concrete compression strain which is taken as 0.005 for unconfined concrete and $0.005 + \frac{1.4\rho_s f_{yh}\varepsilon_{su}}{f_{cc'}}$ for confined concrete.

ρ_s :volumetric ratio of transverse steel hoops to volume of concrete core measured to the outside of peripheral hoop,

f_{cc}' :confined concrete strength,

f_{yh} :yield stress of hoop reinforcement,

ε_{su} :strain at the maximum stress of transverse reinforcement=0.1, for Steel A36. S420 used in the design is a similar material with Steel A36, so this value can be used.

d :depth to the outer layer of tension steel from the extreme compression fiber

d' :distance from the extreme compression fiber to the center of the nearest compression reinforcing bars

d'' :distance from the extreme compression fiber of the cover concrete to the centerline of the perimeter hoop (meanly, c – d" : depth of confined concrete under compression)

ε_b :buckling strain in the longitudinal reinforcement; If $6d_b < s < 30d_b$; $\varepsilon_b=2\frac{f_y}{E_s}$

Where:

f_y: yield strength of longitudinal reinforcement, E_s: modulus of elasticity of longitudinal reinforcement, d_b: diameter of longitudinal reinforcement and s: spacing of the spirals

$\varepsilon_{s,max}$:≤0.1 (taken as 0.1)

ε_{ap} :plastic strain amplitude= $0.08(2N_f)^{-0.5}$ where N_f: effective number of equal-amplitude cycles of loading that lead to fracture=$3.5(T_n)^{-1/3}$ provided that provided that: $2 \leq N_f \leq 10$ and T_n is the natural period of vibration of the bridge.

Φ_y: nominal yield curvature=$\frac{2\varepsilon_y}{D\prime} = \frac{M_n}{I_{eff}E_c}$ where ε_y: yield strain= $\frac{f_y}{E_s}$, D': distance between outer layers of longitudinal reinforcement, M_n: nominal moment, I_{eff}: effective moment of inertia=min[$0.5I_{gross}$;$(0.8M_nd_c)/(E_c\varepsilon_y)$], E_c: modulus of elasticity of concrete, d_c: column dimension in the related direction

For rectangular sections that are doubly reinforced, the neutral axis depth ratio where value of variable "c" can be found is given by:

$$\frac{c}{D}=\frac{\left(\frac{P_e}{f_c{}'A_g}\right)+\left(\frac{\gamma\rho_t f_y/f_c'}{1-2\left(d'/D\right)}\right)}{\alpha\beta_{dsb}+\left(\frac{2\gamma\rho_t f_y/f_c'}{1-2\left(d'/D\right)}\right)}$$ (This equation can be taken for the design) (3.2.1)

For circular sections, the neutral axis depth ratio is as follows:

$$\frac{c}{D}=\frac{1}{\beta_{dsb}}\left[\frac{\left(\frac{P_e}{f_c{}'A_g}\right)+0.5\rho_t\left(f_y/f_c'\right)\left(\frac{1-2\left(c/D\right)}{1-2\left(d'/D\right)}\right)}{1.32\alpha}\right]^{0.725}$$ (Not used)

(3.2.2)

Where:

c :depth to neutral axis

D :overall depth of section

P_e :axial load on the section,

f_c' :expected concrete strength (ultimate),

f_y :expected yield strength of the longitudinal reinforcement,

A_g :gross cross-section area,

d′ :depth from the extreme compression fiber to the center of the compression reinforcement,

ρ_t :volumetric ratio of the longitudinal reinforcement,

α, β_{dsb} :stress block factors for confined concrete defined below:

α :ratio of average concrete stress in compression zone to confined concrete strength= $0.85 + 0.12(K – 1)^{0.4}$, where:

K :strength enhancement factor due to the confining action of the transverse reinforcement, and is given below for circular and rectangular sections (confinement ratio)= $1+\frac{\rho_s f_{yh}}{f'_c}$, (Reddiar, 2009)

β_{dsb} :depth of stress block = $0.85 + 0.13(K – 1)^{0.6}$,

γ :reinforcing steel configuration factor

$\gamma = 0.5$ for square sections with steel placed symmetrically around the perimeter, (not used)

γ = 0.0 for rectangular beam sections with steel lumped at the outer (top and bottom) faces, (not used)

γ = 0.0 for wall section bending about the weak (out-of-plane) axis, (used for earthquake in the longitudinal direction of bridge)

γ = 1.0 for wall sections bending about the strong (in-plane) axis. (used for earthquake in the transverse direction of bridge)

Φ_u :ultimate yield curvature= $\Phi_y + \Phi_p$ (3.2.3)

Δ_e :elastic displacement and when $\Delta_e = \Delta_y$ (at yielding moment);

$\Delta_e = \frac{1}{3}\Phi_y L^2$ where L: shear span or effective height (3.2.4)

Δ_p :nominal yield displacement= $\Phi_p L_p (L-L_p)$ where L_p: equivalent plastic hinge length=$0.08L+4400\varepsilon_y d_b$ (3.2.5)

Δ_u :ultimate displacement= $\Delta_e + \Delta_p$ (3.2.6)

μ_d :ductility capacity= $(\Delta_e + \Delta_p) / \Delta_e$ (3.2.7)

R_{dis} :displacement capacity to demand ratio= Δ_u / Δ_d where Δ_d is displacement demand (3.2.8)

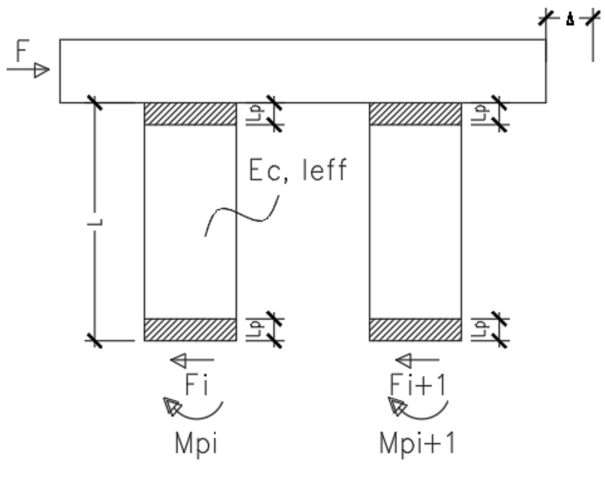


Figure 3.3. Typical Cross-Section View of Bridge and the Represented Parameters Related with the Calculations Above

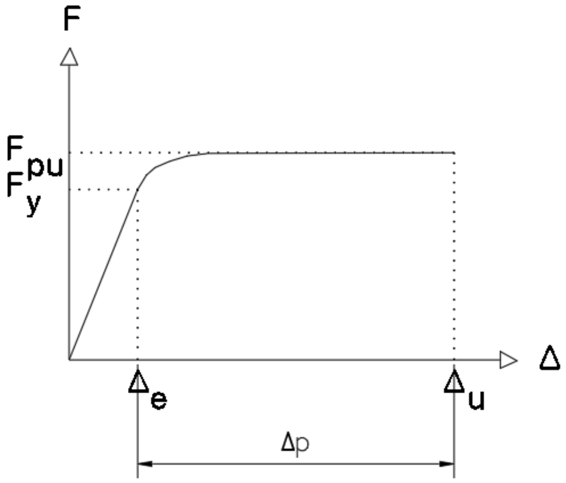


Figure 3.4. Force Displacement Relationship

3.3. Reliability Analysis

Reliability analysis should be performed following the method explained below: (Larsson, Reliability Analysis, 2016)

- If R and S are Normally Distributed, the safety margin M is also normally distributed:

$M=R-S$ (3.3.1)

Where; R is resistance (capacity) and S is demand

- The probability of failure is then:

$P_F=P(R-S<0)=P(M<0)$ (3.3.2)

- The mean value of M:

$\mu_M= \mu_R-\mu_S$ (3.3.3)

- The standard deviation value of M:

$\sigma_M= \sqrt{\sigma_R^2 + \sigma_S^2}$ (3.3.4)

- Coefficient of variation, cov:

$Cov_R(\%)=(\sigma_R/\mu R)x100$ $Cov_S(\%)=(\sigma_S/\mu S)x100$ (3.3.5)

- The reliability index β:

$\beta= \mu_M/\sigma_M$ (3.3.6)

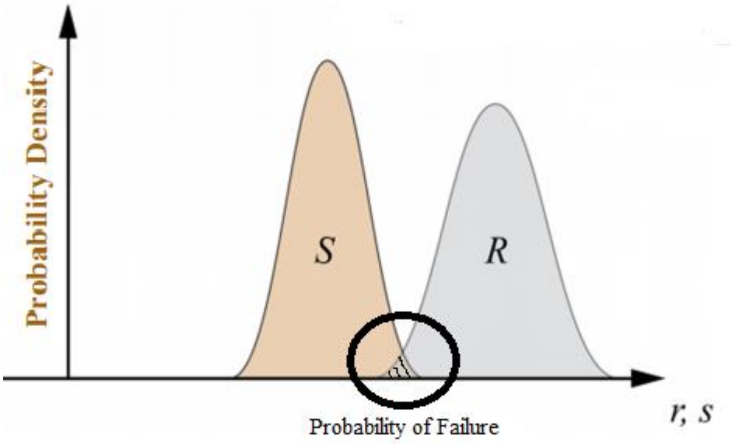


Figure 3.5. Resistance, Demand and Probability of Failure Schema *(Larsson, Reliability Analysis, 2016)*

Using the formulas given above, reliability index of columns designed for different kind of bridges can be calculated. In light of this information, in order to find reliability index values, mean value and standard deviation for column capacity and demand should be determined.

Coefficient of variation (c.o.v) for column moment capacity can be taken from the table below:

Table 3.3. *Input Data for Concrete Column Capacity (Michel Ghosn, 2003)*

	Variable	Bias	Cov	Distribution Type	Reference
	Moment Capacity, M_{col}	1.14	13%	Lognormal	Nowak (1999)
	Axial Capacity, P_{col}	1.05	16%	Lognormal	Ellingwood et al. (1980)
	Shear Capacity no steel, V_{col1}	1.40	17%	Lognormal	Nowak (1999)
	Shear Capacity with steel, V_{col2}	1.20	16%	Lognormal	Nowak (1999)
1*	System capacity for bending of unconfined multicolumn bents, $\lambda_{sys,u}$	1.15	8%	Normal	Liu et al (2001)
2*	System capacity for bending of confined multicolumn bents, $\lambda_{sys,c}$	1.30	13%	Normal	Liu et al (2001)

Cov=0.08 from line 1* is used for unconfined columns. However in the analysis the unconfined sections have been used for single column types (not multicolumn). In order to take this value, it is assumed to be multicolumn.

Cov=0.125 from line 2* is used for confined columns. This type sections have been used for multicolumn type bridges.

Since columns have been designed based on earthquake effect, coefficient of variation (c.o.v) for column moment demand can be taken from the table below:

Table 3.4. *Summary of Input Values for Seismic Reliability Analysis (Michel Ghosn, 2003)*

Variable		Bias	Cov	Distribution Type	Reference
Earthquake modelling, λ_{eq}		1.00	20%	Normal	Ellingwood et al. (1980)
Spectral modelling, *C'*		1.00	varies per site 15% to 40%	Normal	Frankel et al. (1997)
Acceleration, *A*	San Francisco	1.83% g (yearly mean)	333%	-	USGS website
	Seattle	0.89% g (yearly mean)	415%		
	Memphis	0.17% g (yearly mean)	1707%		
	New York	0.066% g (yearly mean)	2121%		
	St. Paul	0.005% g (yearly mean)	3960%		
Period, *t'*		0.90	20%	Lognormal	Chopra and Goel (2000)
Weight, *W*		1.05	5%	Normal	Ellingwood et al. (1980)
Response modification, R_m		7.5 (mean value)	34%	Normal	Priestley and Park (1987) and Liu et al. (1998)

The parts put in rectangle have been used in order to determine the c.o.v for column demand. In addition, as contribution of acceleration, $c.o.v_{acceleration}$=0.333 (given for Bursa which is near to the location planned to design in) (Yılmaz, 2014) Earthquake modeling effect and response modification contribution have not been considered since multimode spectral method has been used in analysis instead of equivalent load method.

The column demand coefficient of variation has been determined as follows:

$$c.o.v=\sqrt{0.3^2+0.33^2+0.2^2+0.05^2}=0.491 \qquad (3.3.7)$$

Where:

$c.o.v_{spectral\text{-}modelling}$=0.3 (taken as a value between 0.15 and 0.40 given in Table 3-4)

$c.o.v_{acceleration}=0.333$

$c.o.v_{period}=0.2$

$c.o.v_{weight}=0.05$

Besides, it is required to indicate that, the mean resistance should be increased by multiplying with the overstrength factor stated in AASHTO LRFD 2010, Section 3.10.9.3. This factor represents the bias capacity. The coefficient of variation for bending capacity is taken from Table 3-3.

$$M_{resistance}=1.3xM_{nominal} \quad (3.3.8)$$

Column reliabilities in terms of moment are calculated as follows:

$$\beta_{moment}= \mu_{M,moment}/\sigma_{M,moment}= \frac{\mu R_{moment}- \mu S_{moment}}{\sqrt{\sigma_{R_{moment}}{}^2+\sigma_{S_{moment}}{}^2}} \quad (3.3.9)$$

Where;

$\mu_{Rmoment}$:Moment resistance calculated by PCA Column Programme based on the sectional properties and axial loads. The results are computed by forming interaction diagram

$\mu_{Smoment}$:Moment demand reached from SAP2000 seismic analysis model

$\sigma_{Rmoment}$:Standard deviation of moment resistance= $\frac{CovR(\%)}{100}x\mu R_{moment}$

$Cov_R(\%)$:Coefficient of variation of column resistance (taken as equal to 12.5 for multiple column bents and 8 for single columns)

$\sigma_{Smoment}$:Standard deviation of moment demand=$\frac{CovS(\%)}{100}x\mu S_{moment}$

$Cov_S(\%)$:Coefficient of variation of column demand (taken as equal to 49.1)

Column reliabilities in terms of displacement are calculated as follows:

$$B_{displacement}= \mu_{M,displacement}/\sigma_{M, displacement} = \frac{\mu R_{\text{displacement}}- \mu S_{\text{displacement}}}{\sqrt{\sigma_{R_{\text{displacement}}}{}^2+\sigma_{S_{\text{displacement}}}{}^2}} \quad (3.3.10)$$

Where;

$\mu_{Rdisplacement}$:Displacement resistance calculated based on pushover analysis

$\mu_{Sdisplacement}$:Displacement demand obtained from SAP2000 seismic analysis model

$\sigma_{Rdisplacement}$:Standard deviation of displacement resistance= $\frac{CovR(\%)}{100} x\mu R_{displacement}$

$Cov_R(\%)$:12.5 for column bents and 8 for single columns (same with moment)

$\sigma_{Sdisplacement}$:Standard deviation of displacement demand= $\frac{CovS(\%)}{100} x\mu S_{displacement}$

$Cov_S(\%)$:49.1 (same with moment)

For normal distribution, probability of exceedance/failure values corresponding to reliability index values are given as follows:

Table 3.5. *Reliability Index (β) and Probability of Exceedance/Failure (Saini & Amarjeet, 2014)*

β	Probability of exceedance/failure
0	0.5
0.5	0.308537539
1	0.158655254
1.5	0.066807201
2	0.022750132
2.5	0.006209665
3	0.001349898
3.5	0.000232629
4	3.16712E-05
4.5	3.3977E-06
5	2.867E-07

CHAPTER 4

ENGINEERING COMPUTATIONS AND RESULTS

4.1. Results of the Computations

Reliability and pushover analysis have been computed based on the equations given in the section 3. The results are given with the quantity and capacity to demand ratio (for moments and displacements) of columns. The detailed calculations are given in Appendix B, C and D. Concrete and reinforcement amounts are given for a cross-section of column. The abbreviation called "C" is the concrete cross sectional area of the column, "R" is the reinforcement area of the cross section of column, "β" is reliability of column and "$\phi M_n/M_u$" is moment capacity to demand ratio of column given in the table below.

Table 4.1. *Reliability, Pushover and Quantity Results for the Columns*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
1	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	22299	33778	67557	33778	67557
	β_{moment,dir_weak}	1.32	0.84	1.93	1.19	1.28	0.79
	$\beta_{moment,dir\_strong}$	3.51	3.51	3.31	3.66	2.44	2.97
	$\beta_{displacement,dir\_weak}$	7.38	7.26	7.28	6.37	7.12	6.12
	$\beta_{displacement,dir\_strong}$	7.88	7.90	7.81	7.67	7.76	7.59
	$\phi M_n/M_{u(weak\ dir.)}$	1.71	1.11	2.07	1.26	1.30	1.09
	$\phi M_n/M_{u(strong\ dir.)}$	2.49	2.49	2.36	2.59	1.85	2.15
2	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	33778	33778	67557	33778	70774
	β_{moment,dir_weak}	0.96	2.10	1.66	0.96	1.05	0.65
	$\beta_{moment,dir\_strong}$	2.78	4.90	2.86	3.11	1.96	2.46
	$\beta_{displacement,dir\_weak}$	7.31	6.93	7.22	6.23	7.05	5.70
	$\beta_{displacement,dir\_strong}$	7.84	7.86	7.77	7.58	7.72	7.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.68	1.47	1.16	1.20	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	2.04	3.69	2.08	2.23	1.61	1.86

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
3	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	33778	33778	67557	33778	80425
	β_{moment,dir_weak}	0.62	1.37	1.42	0.73	0.83	0.61
	$\beta_{moment,dir\_strong}$	1.71	3.78	2.21	2.07	1.35	1.76
	$\beta_{displacement,dir\_weak}$	7.21	6.63	7.14	5.93	6.95	5.21
	$\beta_{displacement,dir\_strong}$	7.79	7.82	7.75	7.45	7.69	7.24
	$\phi M_n/M_{u(weak\ dir.)}$	1.32	1.34	1.36	1.06	1.10	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.49	2.68	1.73	1.66	1.33	1.51
4	C (mm^2)	4017146	4017146	4017146	4017146	4017146	4017146
	R (mm^2)	26546	26546	40212	77208	40212	96510
	β_{moment,dir_weak}	0.92	0.64	1.63	0.66	0.85	0.79
	$\beta_{moment,dir\_strong}$	2.97	3.16	2.77	3.01	1.73	2.99
	$\beta_{displacement,dir\_weak}$	7.43	7.38	7.31	6.47	7.16	6.23
	$\beta_{displacement,dir\_strong}$	7.69	7.71	7.60	7.11	7.50	6.80
	$\phi M_n/M_{u(weak\ dir.)}$	1.14	1.02	1.45	1.03	1.11	1.09
	$\phi M_n/M_{u(strong\ dir.)}$	2.15	2.26	2.03	2.17	1.50	2.16
5	C (mm^2)	4017146	4017146	4017146	4017146	4017146	4017146
	R (mm^2)	26546	29732	40212	77208	40212	96510
	β_{moment,dir_weak}	0.96	0.97	1.62	0.73	0.87	0.85
	$\beta_{moment,dir\_strong}$	2.54	3.15	2.29	2.54	1.36	2.53
	$\beta_{displacement,dir\_weak}$	7.41	7.26	7.29	6.41	7.13	6.16
	$\beta_{displacement,dir\_strong}$	7.65	7.63	7.55	6.97	7.45	6.62
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.16	1.45	1.06	1.12	1.11
	$\phi M_n/M_{u(strong\ dir.)}$	1.90	2.26	1.78	1.91	1.33	1.90
6	C (mm^2)	4017146	4017146	4017146	4017146	4017146	4017146
	R (mm^2)	26546	40212	40212	77208	40212	96510
	β_{moment,dir_weak}	0.73	1.90	1.56	0.73	0.85	0.83
	$\beta_{moment,dir\_strong}$	1.69	3.82	1.87	1.90	0.99	1.85
	$\beta_{displacement,dir\_weak}$	7.34	6.97	7.25	6.33	7.08	6.06
	$\beta_{displacement,dir\_strong}$	7.55	7.50	7.48	6.72	7.36	6.29
	$\phi M_n/M_{u(weak\ dir.)}$	1.06	1.58	1.42	1.06	1.11	1.10
	$\phi M_n/M_{u(strong\ dir.)}$	1.48	2.71	1.56	1.58	1.17	1.56
7	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	22299	33778	57906	33778	70774
	β_{moment,dir_weak}	1.16	1.44	1.83	0.71	0.95	0.65
	$\beta_{moment,dir\_strong}$	2.32	3.00	1.81	2.12	0.92	1.92
	$\beta_{displacement,dir\_weak}$	7.60	7.62	7.47	6.95	7.34	6.74
	$\beta_{displacement,dir\_strong}$	7.52	7.59	7.28	6.67	7.10	6.17
	$\phi M_n/M_{u(weak\ dir.)}$	1.25	1.37	1.55	1.05	1.15	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.79	2.16	1.54	1.69	1.14	1.59
8	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	22299	33778	57906	33778	70774
	β_{moment,dir_weak}	1.34	1.45	1.92	0.81	1.08	0.85
	$\beta_{moment,dir\_strong}$	2.05	2.58	1.80	1.80	0.93	1.69
	$\beta_{displacement,dir\_weak}$	7.55	7.56	7.43	6.80	7.30	6.60
	$\beta_{displacement,dir\_strong}$	7.50	7.54	7.34	6.53	7.19	6.04
	$\phi M_n/M_{u(weak\ dir.)}$	1.32	1.37	1.59	1.09	1.21	1.11
	$\phi M_n/M_{u(strong\ dir.)}$	1.65	1.93	1.53	1.53	1.14	1.48

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
9	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	22299	33778	57906	33778	70774
	β_{moment,dir_weak}	1.43	1.06	2.02	1.00	1.20	1.01
	$\beta_{moment,dir\_strong}$	1.79	1.83	1.95	1.58	1.05	1.49
	$\beta_{displacement,dir\_weak}$	7.51	7.44	7.39	6.71	7.26	6.50
	$\beta_{displacement,dir\_strong}$	7.41	7.38	7.31	6.26	7.17	5.71
	$\phi M_n/M_{u(weak\ dir.)}$	1.36	1.20	1.64	1.17	1.26	1.18
	$\phi M_n/M_{u(strong\ dir.)}$	1.53	1.55	1.61	1.43	1.19	1.39
10	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	25447	31416	31416	53093	38013	53093
	β_{moment,dir_weak}	1.55	1.62	0.98	1.14	1.24	0.72
	$\beta_{moment,dir\_strong}$	2.35	3.40	0.92	2.21	1.20	1.50
	$\beta_{displacement,dir\_weak}$	7.69	7.57	7.69	7.10	7.58	6.96
	$\beta_{displacement,dir\_strong}$	7.87	7.89	7.81	7.75	7.77	7.69
	$\phi M_n/M_{u(weak\ dir.)}$	1.42	1.45	1.17	1.23	1.28	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.81	2.42	1.14	1.73	1.26	1.39
11	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	25447	31416	31416	53093	38013	53093
	β_{moment,dir_weak}	1.36	1.00	1.10	1.06	1.37	0.66
	$\beta_{moment,dir\_strong}$	3.00	3.82	1.98	2.96	2.30	1.98
	$\beta_{displacement,dir\_weak}$	7.65	7.44	7.68	7.02	7.56	6.87
	$\beta_{displacement,dir\_strong}$	7.84	7.86	7.79	7.68	7.74	7.60
	$\phi M_n/M_{u(weak\ dir.)}$	1.33	1.18	1.22	1.20	1.33	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	2.16	2.71	1.62	2.14	1.78	1.62
12	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	31416	53093	38013	80425
	β_{moment,dir_weak}	1.34	1.13	0.65	0.61	0.92	1.02
	$\beta_{moment,dir\_strong}$	2.76	3.65	1.38	1.42	1.65	1.83
	$\beta_{displacement,dir\_weak}$	7.52	7.19	7.62	6.83	7.47	6.56
	$\beta_{displacement,dir\_strong}$	7.79	7.81	7.77	7.57	7.73	7.31
	$\phi M_n/M_{u(weak\ dir.)}$	1.32	1.23	1.04	1.01	1.14	1.18
	$\phi M_n/M_{u(strong\ dir.)}$	2.03	2.59	1.34	1.36	1.46	1.55
13	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	31416	31416	53093	38013	80425
	β_{moment,dir_weak}	1.82	1.18	0.69	0.71	0.94	1.19
	$\beta_{moment,dir\_strong}$	2.63	2.82	0.72	1.66	0.98	1.98
	$\beta_{displacement,dir\_weak}$	7.66	7.57	7.68	7.06	7.56	6.51
	$\beta_{displacement,dir\_strong}$	7.77	7.79	7.72	7.56	7.66	7.32
	$\phi M_n/M_{u(weak\ dir.)}$	1.54	1.25	1.05	1.05	1.15	1.26
	$\phi M_n/M_{u(strong\ dir.)}$	1.95	2.06	1.06	1.47	1.17	1.62
14	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	31416	80425	38013	80425
	β_{moment,dir_weak}	1.47	1.42	0.59	1.46	0.84	0.89
	$\beta_{moment,dir\_strong}$	2.43	3.52	0.91	2.68	1.18	1.77
	$\beta_{displacement,dir\_weak}$	7.61	7.38	7.66	6.53	7.53	6.84
	$\beta_{displacement,dir\_strong}$	7.71	7.72	7.68	7.31	7.61	7.14
	$\phi M_n/M_{u(weak\ dir.)}$	1.38	1.36	1.01	1.38	1.11	1.13
	$\phi M_n/M_{u(strong\ dir.)}$	1.85	2.50	1.14	1.98	1.25	1.52

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
15	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	38013	80425	38013	83642
	β_{moment,dir_weak}	1.04	0.75	1.32	1.12	0.72	0.65
	$\beta_{moment,dir\_strong}$	1.99	2.78	1.93	1.92	1.08	1.08
	$\beta_{displacement,dir\_weak}$	7.52	7.19	7.55	6.83	7.46	6.64
	$\beta_{displacement,dir\_strong}$	7.63	7.60	7.64	7.07	7.57	6.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.19	1.07	1.31	1.23	1.06	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.62	2.04	1.51	1.78	1.23	1.57
16	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	31416	38013	70774	38013	80425
	β_{moment,dir_weak}	1.66	1.08	1.49	0.85	0.74	0.64
	$\beta_{moment,dir\_strong}$	2.52	2.79	1.76	2.31	1.13	1.89
	$\beta_{displacement,dir\_weak}$	7.71	7.67	7.68	7.21	7.61	7.07
	$\beta_{displacement,dir\_strong}$	7.70	7.72	7.67	7.28	7.60	7.04
	$\phi M_n/M_{u(weak\ dir.)}$	1.47	1.21	1.39	1.11	1.07	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.90	2.04	1.51	1.78	1.23	1.57
17	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	31416	38013	70774	41054	90076
	β_{moment,dir_weak}	1.30	0.60	1.30	0.65	0.77	0.76
	$\beta_{moment,dir\_strong}$	1.94	2.05	1.48	1.56	1.01	1.49
	$\beta_{displacement,dir\_weak}$	7.67	.760	7.65	7.11	7.57	6.97
	$\beta_{displacement,dir\_strong}$	7.64	7.64	7.62	7.12	7.52	6.77
	$\phi M_n/M_{u(weak\ dir.)}$	1.31	1.01	1.30	1.03	1.08	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	1.65	1.39	1.42	1.18	1.38
18	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	38013	80425	41054	90076
	β_{moment,dir_weak}	1.10	0.95	1.26	0.91	0.73	0.62
	$\beta_{moment,dir\_strong}$	1.30	2.09	1.20	1.10	0.66	0.60
	$\beta_{displacement,dir\_weak}$	7.59	7.38	7.59	6.94	7.50	6.76
	$\beta_{displacement,dir\_strong}$	7.54	7.46	7.55	6.72	7.43	6.35
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.16	1.29	1.14	1.06	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.31	1.67	1.26	1.22	1.03	1.01
19	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	62832	62832	106186	76027	160850
	β_{moment,dir_weak}	2.13	1.36	0.84	0.81	0.82	1.17
	$\beta_{moment,dir\_strong}$	3.08	3.33	0.93	1.76	0.92	1.95
	$\beta_{displacement,dir\_weak}$	11.88	11.68	11.95	11.41	11.84	11.26
	$\beta_{displacement,dir\_strong}$	12.17	12.24	12.10	11.71	11.99	11.50
	$\phi M_n/M_{u(weak\ dir.)}$	1.62	1.30	1.10	1.08	1.09	1.23
	$\phi M_n/M_{u(strong\ dir.)}$	2.04	2.15	1.13	1.47	1.13	1.55
20	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	62832	62832	106186	76027	160850
	β_{moment,dir_weak}	1.81	0.77	0.81	0.67	0.79	1.03
	$\beta_{moment,dir\_strong}$	2.83	2.97	1.03	1.60	1.02	1.71
	$\beta_{displacement,dir\_weak}$	11.78	11.43	11.89	11.29	11.78	11.13
	$\beta_{displacement,dir\_strong}$	12.00	12.09	11.94	11.24	11.77	10.91
	$\phi M_n/M_{u(weak\ dir.)}$	1.48	1.07	1.08	1.03	1.08	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.93	1.99	1.17	1.40	1.17	1.45

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
21	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	76027	62832	160850	76027	160850
	β_{moment,dir_weak}	1.36	0.83	0.66	1.24	0.64	0.81
	$\beta_{moment,dir\_strong}$	2.49	3.18	1.06	1.85	1.04	1.16
	$\beta_{displacement,dir\_weak}$	11.61	11.19	11.81	11.12	11.69	10.93
	$\beta_{displacement,dir\_strong}$	11.82	11.82	11.82	10.57	11.62	10.08
	$\phi M_n/M_{u(weak\ dir.)}$	1.30	1.09	1.03	1.25	1.02	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.77	2.08	1.18	1.50	1.18	1.22
22	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	62832	62832	106186	76027	160850
	β_{moment,dir_weak}	1.97	1.23	0.78	0.67	0.76	1.02
	$\beta_{moment,dir\_strong}$	2.82	2.96	0.92	1.50	0.91	1.69
	$\beta_{displacement,dir\_weak}$	11.87	11.68	11.92	11.38	11.82	11.22
	$\beta_{displacement,dir\_strong}$	11.95	11.98	11.89	11.09	11.72	10.78
	$\phi M_n/M_{u(weak\ dir.)}$	1.55	1.25	1.07	1.03	1.06	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.92	1.98	1.13	1.36	1.12	1.44
23	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	62832	62832	160850	76027	160850
	β_{moment,dir_weak}	1.57	0.62	0.62	1.23	0.61	0.78
	$\beta_{moment,dir\_strong}$	2.29	2.21	0.79	1.93	0.78	1.23
	$\beta_{displacement,dir\_weak}$	11.77	11.44	11.87	11.28	11.75	11.09
	$\beta_{displacement,dir\_strong}$	11.77	11.78	11.75	10.64	11.53	10.17
	$\phi M_n/M_{u(weak\ dir.)}$	1.39	1.01	1.01	1.25	1.00	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.69	1.65	1.07	1.54	1.07	1.25
24	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	76027	76027	160850	106186	176934
	β_{moment,dir_weak}	1.14	0.70	0.98	0.91	1.97	0.68
	$\beta_{moment,dir\_strong}$	1.76	2.11	1.20	1.18	2.30	0.83
	$\beta_{displacement,dir\_weak}$	11.59	11.19	11.79	11.04	11.72	10.81
	$\beta_{displacement,dir\_strong}$	11.53	11.38	11.53	9.78	11.01	9.22
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.04	1.15	1.12	1.56	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.47	1.61	1.24	1.23	1.69	1.09
25	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	72885	72885	186585	88191	186585
	β_{moment,dir_weak}	1.82	1.18	0.68	1.30	0.91	0.85
	$\beta_{moment,dir\_strong}$	2.71	2.74	0.95	2.67	1.20	1.50
	$\beta_{displacement,dir\_weak}$	11.95	11.82	11.99	11.51	11.91	11.35
	$\beta_{displacement,dir\_strong}$	11.74	11.73	11.71	10.46	11.40	10.00
	$\phi M_n/M_{u(weak\ dir.)}$	1.49	1.23	1.03	1.28	1.12	1.10
	$\phi M_n/M_{u(strong\ dir.)}$	1.87	1.88	1.14	1.66	1.24	1.36
26	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	72885	88191	186585	88191	186585
	β_{moment,dir_weak}	1.48	0.70	1.33	1.06	0.76	0.64
	$\beta_{moment,dir\_strong}$	2.12	1.96	1.58	1.66	0.97	1.01
	$\beta_{displacement,dir\_weak}$	11.88	11.67	11.97	11.42	11.86	11.24
	$\beta_{displacement,dir\_strong}$	11.58	11.51	11.46	10.03	11.24	9.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.35	1.04	1.29	1.18	1.06	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.62	1.55	1.39	1.43	1.15	1.16

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
27	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	88191	88191	186585	123176	209104
	β_{moment,dir_weak}	1.12	0.97	1.12	0.79	1.86	0.61
	$\beta_{moment,dir\_strong}$	1.45	1.95	1.23	0.86	2.01	0.68
	$\beta_{displacement,dir\_weak}$	11.72	11.43	11.87	11.19	11.80	10.99
	$\beta_{displacement,dir\_strong}$	11.27	10.78	11.21	8.98	10.65	8.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.15	1.21	1.07	1.51	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.34	1.55	1.25	1.10	1.57	1.03
28	C (mm^2)	3267146	3267146	3267146	5141593	3267146	5141593
	R (mm^2)	33778	33778	33778	115812	33778	115812
	β_{moment,dir_weak}	1.95	0.81	1.20	1.13	0.64	0.66
	$\beta_{moment,dir\_strong}$	3.87	3.43	2.33	2.64	1.59	1.84
	$\beta_{displacement,dir\_weak}$	6.89	6.37	7.07	3.90	6.87	4.67
	$\beta_{displacement,dir\_strong}$	7.77	7.79	7.74	7.34	7.69	7.17
	$\phi M_n/M_{u(weak\ dir.)}$	1.61	1.10	1.26	1.23	1.03	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	2.75	2.44	1.79	1.96	1.44	1.55
29	C (mm^2)	3267146	3267146	3267146	5141593	3267146	5141593
	R (mm^2)	33778	44598	33778	115812	44598	115812
	β_{moment,dir_weak}	1.59	1.06	1.04	1.25	1.03	0.78
	$\beta_{moment,dir\_strong}$	2.88	3.05	1.75	1.67	1.77	0.89
	$\beta_{displacement,dir\_weak}$	6.74	6.06	7.00	3.72	6.73	4.36
	$\beta_{displacement,dir\_strong}$	7.74	7.69	7.73	7.10	7.61	6.93
	$\phi M_n/M_{u(weak\ dir.)}$	1.43	1.20	1.19	1.28	1.19	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	2.09	2.20	1.51	1.47	1.52	1.13
30	C (mm^2)	3267146	3267146	3267146	5141593	3267146	5141593
	R (mm^2)	33778	44598	33778	115812	44598	115812
	β_{moment,dir_weak}	1.54	1.01	1.03	1.31	1.03	0.86
	$\beta_{moment,dir\_strong}$	2.38	2.45	1.39	1.16	1.36	0.62
	$\beta_{displacement,dir\_weak}$	6.70	6.00	6.98	3.46	6.71	4.29
	$\beta_{displacement,dir\_strong}$	7.69	7.60	7.69	6.91	7.55	6.75
	$\phi M_n/M_{u(weak\ dir.)}$	1.41	1.18	1.19	1.31	1.19	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.82	1.85	1.34	1.24	1.33	1.02
31	C (mm^2)	4017146	4017146	4017146	4017146	4017146	6141593
	R (mm^2)	40212	50969	40212	96510	50969	128680
	β_{moment,dir_weak}	1.89	1.15	1.07	0.64	0.92	0.69
	$\beta_{moment,dir\_strong}$	3.57	3.86	1.74	2.11	1.53	2.08
	$\beta_{displacement,dir\_weak}$	7.04	6.57	7.15	6.11	6.92	5.01
	$\beta_{displacement,dir\_strong}$	7.49	7.32	7.42	6.52	7.17	6.18
	$\phi M_n/M_{u(weak\ dir.)}$	1.58	1.24	1.21	1.03	1.14	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	2.53	2.74	1.50	1.68	1.41	1.67
32	C (mm^2)	4017146	4017146	4017146	4017146	4017146	6141593
	R (mm^2)	40212	40212	40212	96510	40212	128680
	β_{moment,dir_weak}	1.95	0.69	1.21	0.77	0.58	1.12
	$\beta_{moment,dir\_strong}$	2.85	2.23	1.45	1.39	0.63	1.41
	$\beta_{displacement,dir\_weak}$	6.99	6.53	7.15	3.89	6.97	4.97
	$\beta_{displacement,dir\_strong}$	7.37	7.22	7.34	6.14	7.18	5.71
	$\phi M_n/M_{u(weak\ dir.)}$	1.60	1.05	1.27	1.08	1.00	1.23
	$\phi M_n/M_{u(strong\ dir.)}$	2.08	1.74	1.37	1.34	1.02	1.35

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
33	C (mm^2)	4017146	4017146	4017146	4017146	4017146	6141593
	R (mm^2)	40212	40212	40212	96510	50969	128680
	β_{moment,dir_weak}	1.89	0.74	1.22	0.76	1.16	1.14
	$\beta_{moment,dir\_strong}$	2.53	.187	1.27	1.03	1.09	1.26
	$\beta_{displacement,dir\_weak}$	6.97	6.49	7.15	3.87	6.92	4.93
	$\beta_{displacement,dir\_strong}$	7.29	7.09	7.29	5.91	6.98	5.45
	$\phi M_n/M_{u(weak\ dir.)}$	1.57	1.07	1.27	1.07	1.24	1.24
	$\phi M_n/M_{u(strong\ dir.)}$	1.90	1.57	1.29	1.19	1.21	1.29
34	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	33778	33778	67557	33778	77208
	β_{moment,dir_weak}	0.60	1.90	1.74	0.83	0.87	0.63
	$\beta_{moment,dir\_strong}$	1.26	3.85	1.99	1.80	1.05	1.36
	$\beta_{displacement,dir\_weak}$	7.53	7.30	7.44	6.84	7.32	6.64
	$\beta_{displacement,dir\_strong}$	7.41	7.37	7.34	6.29	7.20	5.79
	$\phi M_n/M_{u(weak\ dir.)}$	1.01	1.58	1.50	1.10	1.12	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.29	2.73	1.62	1.53	1.20	1.33
35	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	33778	33778	67557	33778	77208
	β_{moment,dir_weak}	0.90	1.81	2.05	1.16	1.22	0.91
	$\beta_{moment,dir\_strong}$	1.07	2.88	2.19	1.44	1.24	1.02
	$\beta_{displacement,dir\_weak}$	7.47	7.09	7.40	6.73	7.28	6.51
	$\beta_{displacement,dir\_strong}$	7.31	7.10	7.31	5.97	7.16	5.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.13	1.54	1.65	1.24	1.27	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.20	2.10	21.72	1.37	1.28	1.18
36	C (mm^2)	3267146	3267146	3267146	3267146	3267146	3267146
	R (mm^2)	22299	33778	33778	67557	33778	77208
	β_{moment,dir_weak}	0.73	1.67	1.90	1.02	1.10	0.76
	$\beta_{moment,dir\_strong}$	0.88	2.37	2.07	1.22	1.16	0.82
	$\beta_{displacement,dir\_weak}$	7.40	6.96	7.36	6.61	7.22	6.37
	$\beta_{displacement,dir\_strong}$	7.18	6.87	7.23	5.65	7.06	5.02
	$\phi M_n/M_{u(weak\ dir.)}$	1.06	1.47	1.58	1.18	1.22	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.12	1.81	1.66	1.27	1.24	1.10
37	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	31416	53093	38013	80425
	β_{moment,dir_weak}	1.41	1.18	0.78	0.67	1.01	1.00
	$\beta_{moment,dir\_strong}$	3.16	3.93	1.73	2.10	2.02	2.45
	$\beta_{displacement,dir\_weak}$	7.52	7.19	7.62	6.85	7.48	6.33
	$\beta_{displacement,dir\_strong}$	7.80	7.83	7.78	7.62	7.74	7.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.35	1.25	1.08	1.04	1.18	1.18
	$\phi M_n/M_{u(strong\ dir.)}$	2.26	2.79	1.50	1.68	1.64	1.86
38	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	53093	38013	80425	38013	86859
	β_{moment,dir_weak}	0.70	1.66	1.16	0.89	0.62	0.63
	$\beta_{moment,dir\_strong}$	2.33	4.61	2.58	1.78	1.70	1.40
	$\beta_{displacement,dir\_weak}$	7.35	6.68	7.47	6.17	7.36	5.74
	$\beta_{displacement,dir\_strong}$	7.70	7.69	7.72	7.18	7.66	7.02
	$\phi M_n/M_{u(weak\ dir.)}$	1.05	1.47	1.24	1.13	1.02	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.79	3.39	1.93	1.52	1.48	1.35

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
39	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	53093	38013	80425	53093	106161
	β_{moment,dir_weak}	1.19	1.41	0.86	0.65	1.59	0.68
	$\beta_{moment,dir\_strong}$	2.35	3.16	.140	1.04	2.25	1.12
	$\beta_{displacement,dir\_weak}$	7.21	6.61	7.43	5.69	7.19	5.11
	$\beta_{displacement,dir\_strong}$	7.70	7.67	7.73	7.27	7.67	7.03
	$\phi M_n/M_{u(weak\ dir.)}$	1.26	1.35	1.11	1.03	1.43	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.80	2.26	1.35	1.19	1.75	1.23
40	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	38013	38013	80425	38013	106161
	β_{moment,dir_weak}	0.90	0.59	1.20	0.94	0.61	0.84
	$\beta_{moment,dir\_strong}$	1.94	2.76	1.78	1.89	1.08	1.69
	$\beta_{displacement,dir\_weak}$	7.51	7.19	7.56	6.84	7.46	5.04
	$\beta_{displacement,dir\_strong}$	7.62	7.61	7.62	7.09	7.54	6.71
	$\phi M_n/M_{u(weak\ dir.)}$	1.13	1.00	1.26	1.15	1.01	1.11
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	2.02	1.52	1.57	1.21	1.48
41	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	53093	38013	86859	53093	112595
	β_{moment,dir_weak}	1.30	1.38	0.97	0.72	1.76	0.63
	$\beta_{moment,dir\_strong}$	2.69	3.64	1.82	1.47	2.67	1.50
	$\beta_{displacement,dir\_weak}$	7.31	6.79	7.48	5.00	7.26	4.28
	$\beta_{displacement,dir\_strong}$	7.56	7.46	7.61	6.84	7.51	6.49
	$\phi M_n/M_{u(weak\ dir.)}$	1.30	1.34	1.16	1.06	1.52	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.99	2.58	1.54	1.38	1.98	1.39
42	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	53093	38013	86859	53093	122246
	β_{moment,dir_weak}	1.12	1.20	0.85	0.61	1.62	0.65
	$\beta_{moment,dir\_strong}$	1.94	2.54	1.24	0.77	1.98	0.96
	$\beta_{displacement,dir\_weak}$	7.23	6.65	7.44	4.78	7.20	4.08
	$\beta_{displacement,dir\_strong}$	7.47	7.30	7.54	6.62	7.42	6.13
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.26	1.11	1.01	1.45	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	1.90	1.28	1.08	1.62	1.16
43	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	53093	38013	86859	53093	106161
	β_{moment,dir_weak}	0.70	1.86	1.06	0.81	1.82	0.77
	$\beta_{moment,dir\_strong}$	1.29	3.87	1.11	1.31	1.96	1.00
	$\beta_{displacement,dir\_weak}$	7.62	7.30	7.62	7.03	7.46	6.85
	$\beta_{displacement,dir\_strong}$	7.48	7.42	7.49	6.55	7.35	6.00
	$\phi M_n/M_{u(weak\ dir.)}$	1.05	1.56	1.20	1.10	1.54	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.30	2.74	1.22	1.31	1.61	1.18
44	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	53093	38013	86859	53093	106161
	β_{moment,dir_weak}	0.63	1.75	1.10	0.75	1.86	0.78
	$\beta_{moment,dir\_strong}$	0.83	2.84	1.02	0.64	1.77	0.68
	$\beta_{displacement,dir\_weak}$	7.55	7.14	7.58	6.88	7.40	6.70
	$\beta_{displacement,dir\_strong}$	7.42	7.23	7.48	6.34	7.33	5.89
	$\phi M_n/M_{u(weak\ dir.)}$	1.02	1.51	1.22	1.07	1.56	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.10	2.07	1.18	1.03	1.52	1.04

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
45	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	31416	53093	38013	96510	53093	115812
	β_{moment,dir_weak}	0.66	1.77	1.11	1.13	1.90	1.00
	$\beta_{moment,dir\_strong}$	0.59	2.32	0.89	0.80	1.64	0.78
	$\beta_{displacement,dir\_weak}$	7.48	7.01	7.53	6.76	7.34	4.84
	$\beta_{displacement,dir\_strong}$	7.35	7.07	7.44	6.13	7.29	5.65
	$\phi M_n/M_{u(weak\ dir.)}$	1.03	1.52	1.22	1.23	1.58	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.00	1.79	1.13	1.09	1.46	1.08
46	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	76027	62832	160850	76027	160850
	β_{moment,dir_weak}	1.43	0.94	0.72	1.21	0.68	0.77
	$\beta_{moment,dir\_strong}$	2.31	3.03	0.89	1.79	0.87	1.07
	$\beta_{displacement,dir\_weak}$	11.50	11.04	11.72	10.90	11.56	10.65
	$\beta_{displacement,dir\_strong}$	11.87	11.90	11.84	10.80	11.65	10.33
	$\phi M_n/M_{u(weak\ dir.)}$	1.33	1.14	1.05	1.24	1.03	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.70	2.01	1.12	1.48	1.11	1.19
47	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	106186	76027	160850	106186	176934
	β_{moment,dir_weak}	0.86	1.78	0.95	0.84	1.86	0.63
	$\beta_{moment,dir\_strong}$	2.33	4.76	1.75	1.68	2.96	1.36
	$\beta_{displacement,dir\_weak}$	11.23	10.78	11.59	10.60	11.49	10.32
	$\beta_{displacement,dir\_strong}$	11.83	11.48	11.82	10.55	11.45	10.23
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.47	1.14	1.10	1.51	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.71	2.87	1.46	1.43	1.98	1.30
48	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	106186	76027	160850	106186	199453
	β_{moment,dir_weak}	0.61	1.45	0.74	0.64	1.59	0.64
	$\beta_{moment,dir\_strong}$	1.60	3.40	1.17	1.14	2.25	1.07
	$\beta_{displacement,dir\_weak}$	11.07	10.57	11.51	10.42	11.40	10.09
	$\beta_{displacement,dir\_strong}$	11.65	11.04	11.68	10.15	11.24	9.77
	$\phi M_n/M_{u(weak\ dir.)}$	1.00	1.34	1.05	1.02	1.40	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.40	2.19	1.23	1.22	1.67	1.19
49	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	76027	76027	160850	106186	199453
	β_{moment,dir_weak}	1.05	0.65	0.88	0.79	1.82	0.74
	$\beta_{moment,dir\_strong}$	1.59	1.93	1.01	1.05	2.01	0.86
	$\beta_{displacement,dir\_weak}$	11.43	10.98	11.65	10.74	11.55	10.45
	$\beta_{displacement,dir\_strong}$	11.53	11.42	11.51	9.80	10.97	9.17
	$\phi M_n/M_{u(weak\ dir.)}$	1.18	1.02	1.11	1.07	1.49	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.40	1.54	1.16	1.18	1.57	1.11
50	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	62832	106186	76027	160850	106186	199453
	β_{moment,dir_weak}	0.71	1.62	0.78	0.62	1.70	0.62
	$\beta_{moment,dir\_strong}$	1.59	3.45	1.19	1.01	2.26	0.99
	$\beta_{displacement,dir\_weak}$	11.23	10.78	11.58	10.57	11.48	10.28
	$\beta_{displacement,dir\_strong}$	11.43	10.68	11.49	9.51	10.93	9.06
	$\phi M_n/M_{u(weak\ dir.)}$	1.04	1.41	1.07	1.01	1.44	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.39	2.21	1.23	1.16	1.68	1.16

Table 4.1. *Continued*

Analysis number	Parameters	Spectrum Cases Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
51	C (mm^2)	10640000	10640000	10640000	10640000	10640000	10640000
	R (mm^2)	76027	106186	76027	199453	106186	205887
	β_{moment,dir_weak}	1.09	1.44	0.70	0.93	1.59	0.61
	$\beta_{moment,dir\_strong}$	1.78	2.60	0.89	1.15	1.86	0.80
	$\beta_{displacement,dir\_weak}$	11.10	10.57	11.49	10.37	11.38	10.04
	$\beta_{displacement,dir\_strong}$	11.09	10.06	11.31	8.98	10.65	8.44
	$\phi M_n/M_{u(weak\ dir.)}$	1.20	1.33	1.04	1.13	1.40	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.47	1.82	1.12	1.22	1.51	1.08
52	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	88191	88191	186585	123176	225189
	β_{moment,dir_weak}	1.00	0.83	1.09	0.71	1.82	0.63
	$\beta_{moment,dir\_strong}$	1.63	2.12	1.35	1.03	2.11	0.94
	$\beta_{displacement,dir\_weak}$	11.64	11.32	11.81	11.04	11.72	10.82
	$\beta_{displacement,dir\_strong}$	11.25	10.84	11.18	8.96	10.60	8.40
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.09	1.20	1.04	1.49	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.41	1.61	1.30	1.17	1.61	1.13
53	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	123176	88191	225189	123176	247708
	β_{moment,dir_weak}	0.72	1.75	0.93	0.83	1.61	0.62
	$\beta_{moment,dir\_strong}$	1.11	2.70	1.05	0.94	1.77	0.72
	$\beta_{displacement,dir\_weak}$	11.47	11.15	11.72	10.83	11.62	10.56
	$\beta_{displacement,dir\_strong}$	10.95	9.73	10.95	8.24	10.27	7.61
	$\phi M_n/M_{u(weak\ dir.)}$	1.05	1.46	1.13	1.09	1.40	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.20	1.87	1.18	1.13	1.47	1.05
54	C (mm^2)	12040000	12040000	12040000	12040000	12040000	12040000
	R (mm^2)	72885	123176	88191	225189	123176	270227
	β_{moment,dir_weak}	0.64	.159	0.88	0.81	1.54	0.75
	$\beta_{moment,dir\_strong}$	0.76	2.03	0.80	0.70	1.47	0.63
	$\beta_{displacement,dir\_weak}$	11.31	10.91	11.62	10.61	11.50	10.33
	$\beta_{displacement,dir\_strong}$	10.71	9.08	10.81	7.88	10.07	7.20
	$\phi M_n/M_{u(weak\ dir.)}$	1.02	1.40	1.11	1.08	1.38	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.06	1.58	1.08	1.04	1.35	1.01
55	C (mm^2)	5141593	5141593	5141593	7408739	5141593	7408739
	R (mm^2)	53093	80425	53093	151199	80425	183368
	β_{moment,dir_weak}	1.45	1.34	0.90	0.69	1.27	0.69
	$\beta_{moment,dir\_strong}$	2.78	3.53	1.60	1.25	2.02	1.07
	$\beta_{displacement,dir\_weak}$	6.54	5.95	6.83	4.71	6.63	4.20
	$\beta_{displacement,dir\_strong}$	7.76	7.70	7.75	7.27	7.62	7.01
	$\phi M_n/M_{u(weak\ dir.)}$	1.37	1.32	1.13	1.04	1.29	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	2.04	2.50	1.44	1.28	1.64	1.21
56	C (mm^2)	5141593	5141593	5141593	7408739	5141593	7408739
	R (mm^2)	53093	80425	53093	151199	80425	183368
	β_{moment,dir_weak}	1.54	.140	1.03	1.00	1.40	1.07
	$\beta_{moment,dir\_strong}$	2.17	2.58	1.22	0.72	1.60	0.80
	$\beta_{displacement,dir\_weak}$	6.56	5.97	6.88	4.80	6.68	4.33
	$\beta_{displacement,dir\_strong}$	7.74	7.64	7.74	7.18	7.61	6.96
	$\phi M_n/M_{u(weak\ dir.)}$	1.41	1.35	1.19	1.17	1.35	1.20
	$\phi M_n/M_{u(strong\ dir.)}$	1.71	1.93	1.27	1.06	1.44	1.09

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
57	C (mm^2)	5141593	5141593	5141593	7408739	5141593	7408739
	R (mm^2)	53093	80425	53093	167284	80425	196236
	β_{moment,dir_weak}	1.58	1.43	1.06	1.27	1.43	1.18
	$\beta_{moment,dir\_strong}$	1.64	2.01	0.78	0.68	1.15	0.66
	$\beta_{displacement,dir\_weak}$	6.55	5.96	6.86	4.76	6.67	0.97
	$\beta_{displacement,dir\_strong}$	7.69	7.55	7.69	6.93	7.53	5.42
	$\phi M_n/M_{u(weak\ dir.)}$	1.43	1.36	1.20	1.29	1.36	1.25
	$\phi M_n/M_{u(strong\ dir.)}$	1.46	1.63	1.08	1.04	1.24	1.03
58	C (mm^2)	6141593	6141593	6141593	8658739	6141593	8658739
	R (mm^2)	63711	96510	63711	141548	93510	173718
	β_{moment,dir_weak}	1.76	1.62	1.13	0.63	1.56	0.66
	$\beta_{moment,dir\_strong}$	2.87	3.75	1.48	1.24	1.94	1.09
	$\beta_{displacement,dir\_weak}$	6.89	6.45	7.05	5.41	6.89	4.99
	$\beta_{displacement,dir\_strong}$	7.46	7.23	7.42	6.68	7.14	6.20
	$\phi M_n/M_{u(weak\ dir.)}$	1.51	1.45	1.23	1.02	1.42	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	2.09	2.66	1.39	1.28	1.60	1.21
59	C (mm^2)	6141593	6141593	6141593	8658739	6141593	8658739
	R (mm^2)	45616	63711	63711	141548	63711	173718
	β_{moment,dir_weak}	0.68	0.92	1.50	1.09	0.80	1.09
	$\beta_{moment,dir\_strong}$	0.88	1.85	1.46	1.07	0.61	0.95
	$\beta_{displacement,dir\_weak}$	7.08	6.47	7.12	5.58	6.93	5.20
	$\beta_{displacement,dir\_strong}$	7.37	7.22	7.39	6.48	7.25	6.01
	$\phi M_n/M_{u(weak\ dir.)}$	1.04	1.14	1.39	1.21	1.09	1.21
	$\phi M_n/M_{u(strong\ dir.)}$	1.13	1.55	1.37	1.20	1.01	1.16
60	C (mm^2)	6141593	6141593	6141593	8658739	6141593	8658739
	R (mm^2)	48657	63711	63711	141548	93510	173718
	β_{moment,dir_weak}	0.79	0.96	1.45	1.01	1.90	0.97
	$\beta_{moment,dir\_strong}$	0.77	1.71	1.19	0.87	1.66	0.68
	$\beta_{displacement,dir\_weak}$	7.08	6.47	7.12	5.57	6.97	5.19
	$\beta_{displacement,dir\_strong}$	7.30	7.13	7.36	6.34	7.05	5.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.09	1.16	1.37	1.18	1.58	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.08	1.49	1.26	1.12	1.47	1.04
61	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	53093	41054	86859	53093	106161
	β_{moment,dir_weak}	1.43	1.75	0.77	0.68	1.24	0.66
	$\beta_{moment,dir\_strong}$	1.90	3.52	0.87	1.08	1.35	0.85
	$\beta_{displacement,dir\_weak}$	7.49	7.20	7.49	6.90	7.27	6.70
	$\beta_{displacement,dir\_strong}$	7.46	7.36	7.40	6.62	7.27	6.14
	$\phi M_n/M_{u(weak\ dir.)}$	1.36	1.51	1.08	1.04	1.28	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.58	.249	1.12	1.21	1.33	1.11
62	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	41054	38013	86859	53093	106161
	β_{moment,dir_weak}	1.60	0.73	0.68	0.83	1.39	0.79
	$\beta_{moment,dir\_strong}$	1.73	1.30	0.65	0.77	1.39	0.63
	$\beta_{displacement,dir\_weak}$	7.42	7.19	7.45	6.79	7.23	6.57
	$\beta_{displacement,dir\_strong}$	7.35	7.14	7.36	6.36	7.20	5.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.44	1.06	1.04	1.10	1.34	1.09
	$\phi M_n/M_{u(strong\ dir.)}$	1.50	1.31	1.03	1.08	1.34	1.02

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
63	C (mm^2)	5141593	5141593	5141593	5141593	5141593	5141593
	R (mm^2)	38013	42575	42575	96510	53093	122246
	β_{moment,dir_weak}	1.25	0.78	0.94	0.90	1.12	0.94
	$\beta_{moment,dir\_strong}$	1.29	1.20	0.78	0.85	0.93	0.78
	$\beta_{displacement,dir\_weak}$	7.33	6.99	7.36	6.63	7.16	6.38
	$\beta_{displacement,dir\_strong}$	7.22	6.94	7.26	5.98	7.09	5.30
	$\phi M_n/M_{u(weak\ dir.)}$	1.28	1.08	1.15	1.13	1.22	1.15
	$\phi M_n/M_{u(strong\ dir.)}$	1.30	1.26	1.08	1.11	1.15	1.08
64	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	37699	48657	45616	96510	48657	115812
	β_{moment,dir_weak}	0.76	0.66	1.13	0.76	0.69	0.62
	$\beta_{moment,dir\_strong}$	1.96	2.70	1.84	1.53	1.31	1.15
	$\beta_{displacement,dir\_weak}$	7.39	6.97	7.49	5.48	7.38	4.90
	$\beta_{displacement,dir\_strong}$	7.77	7.78	7.77	7.44	7.71	7.29
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.03	1.23	1.08	1.05	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.61	1.99	1.55	1.41	1.31	1.24
65	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	45616	63711	45616	115812	63711	154416
	β_{moment,dir_weak}	0.94	1.10	0.74	0.61	1.41	0.63
	$\beta_{moment,dir\_strong}$	2.12	2.80	1.29	1.06	2.12	0.80
	$\beta_{displacement,dir\_weak}$	7.13	6.47	7.40	4.76	7.15	4.14
	$\beta_{displacement,dir\_strong}$	7.74	7.70	7.74	7.32	7.70	7.06
	$\phi M_n/M_{u(weak\ dir.)}$	1.15	1.22	1.07	1.01	1.36	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.69	2.05	1.30	1.20	1.69	1.09
66	C (mm^2)	6141593	6141593	6141593	6141593	6141593	8658739
	R (mm^2)	45616	63711	45616	154416	63711	183368
	β_{moment,dir_weak}	0.79	0.94	0.61	0.89	1.27	0.79
	$\beta_{moment,dir\_strong}$	1.18	1.26	0.70	0.60	1.28	0.59
	$\beta_{displacement,dir\_weak}$	7.08	6.38	7.37	4.47	7.11	2.88
	$\beta_{displacement,dir\_strong}$	7.65	7.55	7.68	6.95	7.62	6.86
	$\phi M_n/M_{u(weak\ dir.)}$	1.09	1.15	1.01	1.13	1.29	1.09
	$\phi M_n/M_{u(strong\ dir.)}$	1.25	1.29	1.05	1.01	1.30	1.01
67	C (mm^2)	7141593	7141593	7141593	7141593	7141593	8658739
	R (mm^2)	53093	80425	53093	141548	80425	183368
	β_{moment,dir_weak}	1.04	1.18	0.85	0.64	1.81	0.63
	$\beta_{moment,dir\_strong}$	2.30	3.81	1.40	1.43	2.41	1.23
	$\beta_{displacement,dir\_weak}$	7.34	6.86	7.49	4.38	7.29	6.02
	$\beta_{displacement,dir\_strong}$	7.55	7.47	7.58	6.81	7.49	6.53
	$\phi M_n/M_{u(weak\ dir.)}$	1.19	1.25	1.11	1.03	1.54	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.78	2.70	1.35	1.36	1.84	1.27
68	C (mm^2)	7141593	7141593	7141593	7141593	7141593	8658739
	R (mm^2)	53093	80425	53093	151199	80425	193019
	β_{moment,dir_weak}	0.83	0.94	0.68	0.60	1.67	0.64
	$\beta_{moment,dir\_strong}$	1.50	2.39	0.91	0.79	1.83	0.73
	$\beta_{displacement,dir\_weak}$	7.22	6.65	7.44	4.07	7.21	4.16
	$\beta_{displacement,dir\_strong}$	7.43	7.26	.751	6.49	7.39	6.19
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.15	1.04	1.01	1.47	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.40	1.82	1.14	1.09	1.55	1.06

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
69	C (mm^2)	7141593	7141593	7141593	8658739	7141593	8658739
	R (mm^2)	53093	80425	59464	173718	80425	221972
	β_{moment,dir_weak}	0.79	0.97	1.10	1.05	1.62	0.99
	$\beta_{moment,dir\_strong}$	0.74	1.45	0.82	0.64	1.17	0.58
	$\beta_{displacement,dir\_weak}$	7.19	6.60	7.39	6.05	7.19	4.20
	$\beta_{displacement,dir\_strong}$	7.33	7.10	7.45	6.32	7.31	5.79
	$\phi M_n/M_{u(weak\ dir.)}$	1.09	1.16	1.22	1.20	1.45	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.07	1.37	1.10	1.02	1.25	1.00
70	C (mm^2)	5141593	5141593	5141593	5141593	5141593	7408739
	R (mm^2)	38013	53093	38013	112595	53093	167284
	β_{moment,dir_weak}	0.85	0.67	0.71	0.60	1.34	0.90
	$\beta_{moment,dir\_strong}$	1.69	2.67	0.90	0.80	1.59	0.89
	$\beta_{displacement,dir\_weak}$	7.49	7.15	7.58	4.82	7.41	6.38
	$\beta_{displacement,dir\_strong}$	7.34	7.21	7.40	5.97	7.24	5.38
	$\phi M_n/M_{u(weak\ dir.)}$	1.11	1.04	1.06	1.01	1.32	1.13
	$\phi M_n/M_{u(strong\ dir.)}$	1.48	1.98	1.13	1.09	1.43	1.13
71	C (mm^2)	5141593	5141593	5141593	5141593	5141593	7408739
	R (mm^2)	38013	53093	38013	112595	53093	151199
	β_{moment,dir_weak}	0.94	0.75	0.86	0.72	1.51	0.86
	$\beta_{moment,dir\_strong}$	1.25	1.48	0.84	0.78	1.50	0.69
	$\beta_{displacement,dir\_weak}$	7.38	6.93	7.53	4.52	7.33	6.16
	$\beta_{displacement,dir\_strong}$	7.27	6.96	7.40	5.96	7.25	5.50
	$\phi M_n/M_{u(weak\ dir.)}$	1.15	1.07	1.11	1.06	1.40	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.28	1.39	1.11	1.08	1.39	1.05
72	C (mm^2)	5141593	5141593	5141593	5141593	5141593	7408739
	R (mm^2)	41054	53093	41054	154416	53093	167284
	β_{moment,dir_weak}	1.25	0.78	1.00	1.01	1.36	0.95
	$\beta_{moment,dir\_strong}$	0.91	0.63	0.63	0.62	0.92	0.60
	$\beta_{displacement,dir\_weak}$	7.25	6.73	7.44	4.32	7.23	5.87
	$\beta_{displacement,dir\_strong}$	7.07	6.64	7.26	.521	7.09	4.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.28	1.08	1.18	1.33	1.15	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.14	1.02	1.02	1.02	1.14	1.01
73	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	109478	109478	231623	109478	244491
	β_{moment,dir_weak}	1.06	0.75	1.32	0.89	0.75	0.60
	$\beta_{moment,dir\_strong}$	2.46	3.13	2.19	1.70	1.49	1.30
	$\beta_{displacement,dir\_weak}$	11.03	10.38	11.43	10.24	11.20	9.89
	$\beta_{displacement,dir\_strong}$	11.82	.1169	11.75	10.51	11.59	10.19
	$\phi M_n/M_{u(weak\ dir.)}$	1.18	1.06	1.29	1.12	1.06	1.00
	$\phi M_n/M_{u(strong\ dir.)}$	1.76	2.06	1.64	1.44	1.36	1.28
74	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	152908	109478	231623	152908	289529
	β_{moment,dir_weak}	0.67	1.47	1.01	0.61	1.63	0.62
	$\beta_{moment,dir\_strong}$	1.68	3.46	1.65	1.20	2.45	1.12
	$\beta_{displacement,dir\_weak}$	10.80	10.23	11.31	10.00	11.17	9.63
	$\beta_{displacement,dir\_strong}$	11.71	11.13	11.68	10.32	11.32	9.94
	$\phi M_n/M_{u(weak\ dir.)}$	1.03	1.35	1.16	1.01	1.41	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.44	2.22	1.42	1.24	1.76	1.20

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
75	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	152908	109478	238057	152908	302397
	β_{moment,dir_weak}	0.61	1.37	0.94	0.60	1.54	0.62
	$\beta_{moment,dir\_strong}$	1.08	2.30	1.10	0.74	1.79	0.71
	$\beta_{displacement,dir\_weak}$	10.72	10.10	11.26	9.86	11.11	9.46
	$\beta_{displacement,dir\_strong}$	11.45	10.48	11.45	9.69	10.99	9.23
	$\phi M_n/M_{u(weak\ dir.)}$	1.01	1.31	1.14	1.00	1.38	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.19	1.69	1.20	1.06	1.48	1.05
76	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	109478	109478	238057	109478	302397
	β_{moment,dir_weak}	0.93	0.69	1.17	0.74	0.63	0.75
	$\beta_{moment,dir\_strong}$	1.78	2.25	1.63	1.13	1.02	1.14
	$\beta_{displacement,dir\_weak}$	11.08	10.48	11.44	10.26	11.22	9.91
	$\beta_{displacement,dir\_strong}$	11.51	11.23	11.45	9.64	11.23	9.20
	$\phi M_n/M_{u(weak\ dir.)}$	1.13	1.04	1.23	1.06	1.01	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.47	1.67	1.41	1.21	1.17	1.21
77	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	152908	109478	238057	152908	302397
	β_{moment,dir_weak}	0.73	1.63	1.08	0.66	1.74	0.68
	$\beta_{moment,dir\_strong}$	1.46	3.03	1.48	1.02	2.22	1.02
	$\beta_{displacement,dir\_weak}$	10.87	10.35	11.33	10.00	11.18	9.64
	$\beta_{displacement,dir\_strong}$	11.33	10.43	11.34	9.32	10.82	8.82
	$\phi M_n/M_{u(weak\ dir.)}$	1.05	1.41	1.19	1.03	1.46	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.34	2.01	1.35	1.17	1.66	1.17
78	C (mm^2)	15040000	15040000	15040000	15040000	15040000	15040000
	R (mm^2)	90478	152908	109478	244491	152908	308831
	β_{moment,dir_weak}	0.71	1.57	1.04	0.69	1.69	0.69
	$\beta_{moment,dir\_strong}$	0.93	2.02	0.96	0.62	1.61	0.62
	$\beta_{displacement,dir\_weak}$	10.76	10.16	11.25	9.83	11.09	9.41
	$\beta_{displacement,dir\_strong}$	10.98	9.52	11.04	8.50	10.38	7.87
	$\phi M_n/M_{u(weak\ dir.)}$	1.04	1.39	1.17	1.04	1.44	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.13	1.57	1.14	1.01	1.40	1.01
79	C (mm^2)	16640000	16640000	16640000	16640000	16640000	16640000
	R (mm^2)	100531	121642	121642	263793	169897	334567
	β_{moment,dir_weak}	0.88	0.73	1.04	0.61	1.73	0.61
	$\beta_{moment,dir\_strong}$	1.18	1.58	1.03	0.60	1.71	0.61
	$\beta_{displacement,dir\_weak}$	11.39	.1102	11.61	10.64	11.51	10.34
	$\beta_{displacement,dir\_strong}$	11.03	10.57	10.95	8.25	10.26	7.59
	$\phi M_n/M_{u(weak\ dir.)}$	1.11	1.05	1.17	1.01	1.45	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.23	1.39	1.17	1.00	1.44	1.00
80	C (mm^2)	16640000	16640000	16640000	16640000	16640000	16640000
	R (mm^2)	100531	121642	121642	263793	121642	334567
	β_{moment,dir_weak}	0.93	0.73	1.18	0.73	0.63	0.74
	$\beta_{moment,dir\_strong}$	1.19	1.18	1.20	0.75	0.65	0.77
	$\beta_{displacement,dir\_weak}$	11.29	10.82	11.58	10.56	11.39	10.22
	$\beta_{displacement,dir\_strong}$	11.13	10.35	11.17	8.84	10.88	8.29
	$\phi M_n/M_{u(weak\ dir.)}$	1.13	1.05	1.23	1.05	1.01	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.24	1.23	1.24	1.06	1.02	1.07

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
81	C (mm^2)	16640000	16640000	16640000	16640000	16640000	16640000
	R (mm^2)	100531	121642	121642	302397	169897	366737
	β_{moment,dir_weak}	0.86	0.64	1.07	0.86	1.76	0.80
	$\beta_{moment,dir\_strong}$	0.78	0.66	0.82	0.64	1.46	0.60
	$\beta_{displacement,dir\_weak}$	11.05	10.44	11.42	10.19	11.28	9.84
	$\beta_{displacement,dir\_strong}$	10.74	9.61	10.84	7.93	10.10	7.26
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.02	1.19	1.10	1.47	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.07	1.03	1.09	1.02	1.34	1.00
82	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	37699	37699	45616	96510	63711	128680
	β_{moment,dir_weak}	1.10	0.96	0.75	0.93	1.51	1.26
	$\beta_{moment,dir\_strong}$	3.00	3.28	1.67	3.09	2.50	3.35
	$\beta_{displacement,dir\_weak}$	7.40	7.36	7.32	6.34	7.04	6.08
	$\beta_{displacement,dir\_strong}$	7.92	7.93	7.88	7.80	7.83	7.72
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.16	1.07	1.15	1.40	1.29
	$\phi M_n/M_{u(strong\ dir.)}$	2.16	2.33	1.47	2.22	1.89	2.38
83	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	37699	37699	45616	96510	63711	128680
	β_{moment,dir_weak}	1.04	0.79	0.70	0.88	1.45	1.21
	$\beta_{moment,dir\_strong}$	2.68	2.89	1.40	2.81	2.29	3.03
	$\beta_{displacement,dir\_weak}$	7.38	7.31	7.30	6.29	7.02	6.02
	$\beta_{displacement,dir\_strong}$	7.91	7.92	7.86	7.79	7.82	7.69
	$\phi M_n/M_{u(weak\ dir.)}$	1.19	1.09	1.05	1.12	1.37	1.27
	$\phi M_n/M_{u(strong\ dir.)}$	1.98	2.10	1.35	2.06	1.77	2.18
84	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	37699	45616	45616	96510	63711	128680
	β_{moment,dir_weak}	0.96	1.35	0.71	0.88	1.46	1.21
	$\beta_{moment,dir\_strong}$	2.03	3.24	1.18	2.24	2.04	2.43
	$\beta_{displacement,dir\_weak}$	7.36	7.14	7.31	6.30	7.02	6.03
	$\beta_{displacement,dir\_strong}$	7.90	7.92	7.86	7.77	7.82	7.66
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.33	1.05	1.13	1.38	1.26
	$\phi M_n/M_{u(strong\ dir.)}$	1.64	2.31	1.25	1.75	1.65	1.84
85	C (mm^2)	7141593	7141593	7141593	7141593	7141593	7141593
	R (mm^2)	38013	38013	53093	102944	80425	128680
	β_{moment,dir_weak}	0.70	0.85	0.76	0.72	1.77	0.78
	$\beta_{moment,dir\_strong}$	2.13	2.63	1.37	2.52	2.41	2.47
	$\beta_{displacement,dir\_weak}$	7.50	7.52	7.40	6.56	7.17	6.29
	$\beta_{displacement,dir\_strong}$	7.68	7.72	7.55	7.16	7.39	6.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.05	1.11	1.08	1.06	1.52	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.69	1.95	1.34	1.89	1.84	1.87
86	C (mm^2)	7141593	7141593	7141593	7141593	7141593	7141593
	R (mm^2)	38013	38013	53093	102944	80425	128680
	β_{moment,dir_weak}	0.82	0.88	0.86	0.84	1.91	0.97
	$\beta_{moment,dir\_strong}$	2.04	2.40	1.36	2.35	2.40	2.38
	$\beta_{displacement,dir\_weak}$	7.50	7.51	7.41	6.54	7.17	6.31
	$\beta_{displacement,dir\_strong}$	7.67	7.70	7.56	7.10	7.40	6.78
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.12	1.12	1.11	1.58	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.65	1.83	1.33	1.80	1.83	1.82

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
87	C (mm^2)	7141593	7141593	7141593	7141593	7141593	7141593
	R (mm^2)	38013	38013	53093	102944	80425	128680
	β_{moment,dir_weak}	0.96	0.72	0.95	1.09	2.03	1.20
	$\beta_{moment,dir\_strong}$	1.80	1.86	1.20	2.16	2.28	2.18
	$\beta_{displacement,dir\_weak}$	7.52	7.47	7.43	6.64	7.21	6.42
	$\beta_{displacement,dir\_strong}$	7.64	7.64	7.53	7.03	7.36	6.68
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.06	1.15	1.21	1.64	1.26
	$\phi M_n/M_{u(strong\ dir.)}$	1.53	1.56	1.26	1.71	1.77	1.72
88	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	30536	26465	45616	63711	63711	96510
	β_{moment,dir_weak}	1.09	1.01	1.24	0.79	2.11	1.24
	$\beta_{moment,dir\_strong}$	1.79	1.83	1.13	1.66	1.89	2.11
	$\beta_{displacement,dir\_weak}$	7.69	7.75	7.57	7.16	7.38	6.97
	$\beta_{displacement,dir\_strong}$	7.61	7.68	7.38	7.13	7.16	6.62
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.18	1.28	1.09	1.68	1.28
	$\phi M_n/M_{u(strong\ dir.)}$	1.53	1.55	1.23	1.47	1.58	1.68
89	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	30536	26465	45616	63711	63711	96510
	β_{moment,dir_weak}	1.17	.096	1.27	0.77	2.13	1.18
	$\beta_{moment,dir\_strong}$	1.61	1.53	.109	1.37	1.86	1.80
	$\beta_{displacement,dir\_weak}$	7.65	7.71	7.54	7.02	7.35	6.80
	$\beta_{displacement,dir\_strong}$	7.57	7.64	7.38	7.00	7.16	6.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.25	1.16	1.29	1.08	1.69	1.25
	$\phi M_n/M_{u(strong\ dir.)}$	1.44	1.41	1.21	1.34	1.56	1.53
90	C (mm^2)	6141593	6141593	6141593	6141593	6141593	6141593
	R (mm^2)	30536	26465	45616	63711	63711	96510
	β_{moment,dir_weak}	1.21	0.67	1.24	0.71	2.09	1.37
	$\beta_{moment,dir\_strong}$	1.50	1.14	1.04	1.13	1.89	1.76
	$\beta_{displacement,dir\_weak}$	7.65	7.67	7.54	6.96	7.34	6.83
	$\beta_{displacement,dir\_strong}$	7.54	7.58	7.36	6.87	7.16	6.33
	$\phi M_n/M_{u(weak\ dir.)}$	1.27	1.04	1.28	1.06	1.67	1.34
	$\phi M_n/M_{u(strong\ dir.)}$	1.39	1.24	1.19	1.23	1.58	1.52
91	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	31554	36644	45239	76454	54739	76454
	β_{moment,dir_weak}	0.95	0.94	1.01	1.07	1.28	0.66
	$\beta_{moment,dir\_strong}$	1.99	2.87	1.29	2.52	1.59	1.78
	$\beta_{displacement,dir\_weak}$	7.66	7.53	7.63	6.92	7.50	6.75
	$\beta_{displacement,dir\_strong}$	7.87	7.90	7.81	7.74	7.76	7.67
	$\phi M_n/M_{u(weak\ dir.)}$	1.15	1.15	1.18	1.20	1.29	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.62	2.09	1.30	1.89	1.43	1.52
92	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	31554	45239	45239	76454	54739	80701
	β_{moment,dir_weak}	0.75	1.02	1.03	0.95	1.30	0.67
	$\beta_{moment,dir\_strong}$	2.15	3.81	1.75	2.79	2.04	2.01
	$\beta_{displacement,dir\_weak}$	7.62	7.38	7.62	6.84	7.48	6.66
	$\beta_{displacement,dir\_strong}$	7.83	7.85	7.76	7.64	7.70	7.52
	$\phi M_n/M_{u(weak\ dir.)}$	1.07	1.19	1.19	1.16	1.30	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.70	2.70	1.51	2.04	1.65	1.63

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
93	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	45239	54739	45239	80701	54739	96510
	β_{moment,dir_weak}	1.33	1.16	0.60	0.65	0.84	0.64
	$\beta_{moment,dir\_strong}$	2.75	3.66	1.26	.181	1.54	1.49
	$\beta_{displacement,dir\_weak}$	7.46	7.09	7.55	6.64	7.38	6.47
	$\beta_{displacement,dir\_strong}$	7.79	7.84	7.78	7.61	7.73	7.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.32	1.24	1.01	1.03	1.11	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	2.02	2.59	1.29	1.54	1.41	1.39
94	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	44787	44787	55292	93444	66903	122246
	β_{moment,dir_weak}	1.21	0.70	0.95	0.72	1.09	0.91
	$\beta_{moment,dir\_strong}$	2.60	2.69	1.55	2.36	1.68	2.40
	$\beta_{displacement,dir\_weak}$	7.62	7.54	7.60	6.87	7.47	6.72
	$\beta_{displacement,dir\_strong}$	7.76	7.77	7.70	7.48	7.62	7.28
	$\phi M_n/M_{u(weak\ dir.)}$	1.27	1.05	1.16	1.06	1.21	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.93	1.98	1.41	1.81	1.48	1.83
95	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	44787	55292	55292	102944	66903	122246
	β_{moment,dir_weak}	0.93	1.07	0.81	0.77	0.95	0.71
	$\beta_{moment,dir\_strong}$	2.04	3.10	1.24	2.08	1.31	1.79
	$\beta_{displacement,dir\_weak}$	7.58	7.40	7.58	6.82	7.45	6.64
	$\beta_{displacement,dir\_strong}$	7.70	7.69	7.64	7.34	7.55	7.11
	$\phi M_n/M_{u(weak\ dir.)}$	1.14	1.21	1.10	1.08	1.15	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	1.65	2.23	1.28	1.67	1.31	1.53
96	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	44787	66903	55292	102944	66903	128680
	β_{moment,dir_weak}	0.69	1.25	0.72	0.62	0.85	0.70
	$\beta_{moment,dir\_strong}$	1.59	3.27	1.11	1.60	1.17	1.49
	$\beta_{displacement,dir\_weak}$	7.53	7.18	7.54	6.71	7.40	6.51
	$\beta_{displacement,dir\_strong}$	7.64	7.59	7.61	7.22	7.51	6.92
	$\phi M_n/M_{u(weak\ dir.)}$	1.04	1.28	1.06	1.02	1.11	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	1.43	2.33	1.22	1.44	1.25	1.39
97	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	36644	36644	45239	90076	54739	115812
	β_{moment,dir_weak}	0.94	0.66	0.61	0.61	0.81	0.78
	$\beta_{moment,dir\_strong}$	1.90	2.18	1.03	2.05	1.31	2.06
	$\beta_{displacement,dir\_weak}$	7.67	7.65	7.66	7.03	7.53	6.87
	$\beta_{displacement,dir\_strong}$	7.68	7.70	7.62	7.20	7.53	6.87
	$\phi M_n/M_{u(weak\ dir.)}$	1.15	1.04	1.01	1.01	1.09	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.58	1.72	1.19	1.65	1.31	1.66
98	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	36644	45239	54739	96510	54739	115812
	β_{moment,dir_weak}	0.83	1.13	1.41	0.73	0.73	0.70
	$\beta_{moment,dir\_strong}$	1.41	2.40	1.70	1.69	1.02	1.47
	$\beta_{displacement,dir\_weak}$	7.64	7.56	7.58	6.94	7.49	6.77
	$\beta_{displacement,dir\_strong}$	7.62	7.60	7.57	7.01	7.47	6.68
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.23	1.36	1.06	1.06	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	1.36	1.83	1.48	1.48	1.19	1.38

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
99	C (mm^2)	7408739	7408739	7408739	7408739	7408739	7408739
	R (mm^2)	36644	45239	54739	96510	54739	115812
	β_{moment,dir_weak}	0.65	0.71	1.36	0.72	0.72	0.67
	$\beta_{moment,dir\_strong}$	0.97	1.60	1.53	1.15	0.80	0.93
	$\beta_{displacement,dir\_weak}$	7.59	7.45	7.54	6.83	7.45	6.63
	$\beta_{displacement,dir\_strong}$	7.54	7.46	7.51	6.77	7.40	6.36
	$\phi M_n/M_{u(weak\ dir.)}$	1.03	1.05	1.33	1.06	1.06	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.16	1.44	1.41	1.24	1.09	1.15
100	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	106877	131947	131947	222990	159656	337784
	β_{moment,dir_weak}	1.12	1.43	0.86	0.74	0.98	1.13
	$\beta_{moment,dir\_strong}$	2.51	4.21	1.38	2.49	1.58	2.71
	$\beta_{displacement,dir\_weak}$	11.78	11.63	11.87	11.19	11.76	11.01
	$\beta_{displacement,dir\_strong}$	12.22	12.24	12.06	11.74	11.91	11.55
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.33	1.10	1.06	1.15	1.21
	$\phi M_n/M_{u(strong\ dir.)}$	1.79	2.58	1.31	1.78	1.39	1.87
101	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	106877	131947	131947	222990	159656	337784
	β_{moment,dir_weak}	0.90	0.90	0.81	0.61	0.93	1.00
	$\beta_{moment,dir\_strong}$	2.04	3.71	1.18	2.18	1.37	2.30
	$\beta_{displacement,dir\_weak}$	11.71	11.44	11.84	11.10	11.73	10.91
	$\beta_{displacement,dir\_strong}$	12.09	12.12	11.91	11.36	11.70	11.07
	$\phi M_n/M_{u(weak\ dir.)}$	1.12	1.12	1.08	1.01	1.13	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.58	2.33	1.23	1.64	1.31	1.69
102	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	131947	159656	159656	337784	159656	337784
	β_{moment,dir_weak}	1.35	1.01	1.22	1.12	0.67	0.70
	$\beta_{moment,dir\_strong}$	2.89	3.93	2.03	2.59	1.37	1.78
	$\beta_{displacement,dir\_weak}$	11.59	11.21	11.77	10.96	11.61	10.72
	$\beta_{displacement,dir\_strong}$	12.02	12.05	11.91	11.32	11.78	10.99
	$\phi M_n/M_{u(weak\ dir.)}$	1.30	1.16	1.25	1.21	1.03	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.95	2.44	1.58	1.82	1.31	1.47
103	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	106877	131947	131947	337784	159656	337784
	β_{moment,dir_weak}	0.86	1.17	0.68	1.28	0.80	0.85
	$\beta_{moment,dir\_strong}$	1.95	3.38	1.23	2.87	1.41	2.07
	$\beta_{displacement,dir\_weak}$	11.73	11.59	11.82	11.11	11.70	10.89
	$\beta_{displacement,dir\_strong}$	11.94	11.88	11.77	10.87	11.52	10.49
	$\phi M_n/M_{u(weak\ dir.)}$	1.10	1.23	1.03	1.27	1.08	1.10
	$\phi M_n/M_{u(strong\ dir.)}$	1.54	2.18	1.25	1.94	1.32	1.60
104	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	106877	131947	159656	337784	159656	337784
	β_{moment,dir_weak}	0.63	0.74	1.21	1.10	0.66	0.69
	$\beta_{moment,dir\_strong}$	1.36	2.57	1.69	2.27	1.07	1.54
	$\beta_{displacement,dir\_weak}$	11.65	11.42	11.80	11.02	11.65	10.79
	$\beta_{displacement,dir\_strong}$	11.83	11.73	11.58	10.56	11.38	10.10
	$\phi M_n/M_{u(weak\ dir.)}$	1.01	1.06	1.24	1.20	1.02	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.30	1.81	1.44	1.68	1.19	1.37

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
105	C (mm^2)	22260000	22260000	22260000	22260000	22260000	22260000
	R (mm^2)	131947	159656	159656	337784	159656	337784
	β_{moment,dir_weak}	1.31	0.94	1.18	1.01	0.64	0.61
	$\beta_{moment,dir\_strong}$	2.08	2.85	1.48	1.72	0.90	1.05
	$\beta_{displacement,dir\_weak}$	11.59	11.21	11.76	10.93	11.60	10.68
	$\beta_{displacement,dir\_strong}$	11.57	11.38	11.48	10.10	11.26	9.54
	$\phi M_n/M_{u(weak\ dir.)}$	1.28	1.14	1.23	1.16	1.02	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	1.93	1.35	1.45	1.12	1.18
106	C (mm^2)	28660000	28660000	28660000	28660000	28660000	28660000
	R (mm^2)	139449	172159	208313	440728	290949	476115
	β_{moment,dir_weak}	0.70	1.22	1.14	0.93	1.92	0.61
	$\beta_{moment,dir\_strong}$	1.38	2.42	1.45	1.94	2.22	1.37
	$\beta_{displacement,dir\_weak}$	11.91	11.88	11.97	11.27	11.82	11.08
	$\beta_{displacement,dir\_strong}$	11.40	11.33	11.08	9.22	10.46	8.57
	$\phi M_n/M_{u(weak\ dir.)}$	1.04	1.25	1.21	1.13	1.53	1.00
	$\phi M_n/M_{u(strong\ dir.)}$	1.31	1.75	1.34	1.54	1.66	1.31
107	C (mm^2)	28660000	28660000	28660000	28660000	28660000	28660000
	R (mm^2)	139449	172159	208313	440728	208313	440728
	β_{moment,dir_weak}	0.79	1.17	1.20	1.05	0.66	0.64
	$\beta_{moment,dir\_strong}$	1.14	2.00	1.29	1.69	0.73	1.09
	$\beta_{displacement,dir\_weak}$	11.88	11.82	11.95	11.24	11.83	11.04
	$\beta_{displacement,dir\_strong}$	11.30	11.13	10.98	8.89	10.65	8.21
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.23	1.24	1.18	1.02	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.21	1.57	1.28	1.44	1.05	1.19
108	C (mm^2)	28660000	28660000	28660000	28660000	28660000	28660000
	R (mm^2)	139449	172159	208313	440728	290949	440728
	β_{moment,dir_weak}	0.76	0.96	1.22	1.11	2.02	0.69
	$\beta_{moment,dir\_strong}$	0.83	1.52	1.14	1.43	1.92	0.84
	$\beta_{displacement,dir\_weak}$	11.82	11.67	11.92	11.18	11.78	10.97
	$\beta_{displacement,dir\_strong}$	11.10	10.73	10.83	8.37	10.12	7.62
	$\phi M_n/M_{u(weak\ dir.)}$	1.06	1.14	1.25	1.20	1.57	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.09	1.37	1.21	1.33	1.53	1.10
109	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	55292	66903	66903	122246	93444	147982
	β_{moment,dir_weak}	1.11	1.18	0.82	0.65	1.61	0.66
	$\beta_{moment,dir\_strong}$	2.17	3.10	1.27	1.81	2.13	1.65
	$\beta_{displacement,dir\_weak}$	7.31	7.05	7.30	6.31	7.01	6.02
	$\beta_{displacement,dir\_strong}$	7.90	7.91	7.87	7.80	7.84	7.71
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.25	1.10	1.03	1.44	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.71	2.23	1.29	1.54	1.69	1.46
110	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	55292	55292	66903	122246	93444	147982
	β_{moment,dir_weak}	1.43	0.64	1.15	1.02	1.98	0.99
	$\beta_{moment,dir\_strong}$	1.82	1.69	1.21	1.34	2.06	1.15
	$\beta_{displacement,dir\_weak}$	7.38	7.17	7.38	6.52	7.12	6.25
	$\beta_{displacement,dir\_strong}$	7.90	7.91	7.87	7.77	7.83	7.68
	$\phi M_n/M_{u(weak\ dir.)}$	1.36	1.02	1.24	1.18	1.62	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.54	1.48	1.27	1.32	1.66	1.24

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
111	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	55292	55292	66903	122246	93444	147982
	β_{moment,dir_weak}	1.49	0.70	1.23	1.08	2.07	1.02
	$\beta_{moment,dir\_strong}$	1.74	1.53	1.18	1.19	2.02	0.98
	$\beta_{displacement,dir\_weak}$	7.40	7.19	7.40	6.57	7.15	6.29
	$\beta_{displacement,dir\_strong}$	7.89	7.91	7.87	7.76	7.83	7.65
	$\phi M_n/M_{u(weak\ dir.)}$	1.39	1.05	1.27	1.21	1.66	1.18
	$\phi M_n/M_{u(strong\ dir.)}$	1.51	1.41	1.25	1.26	1.64	1.17
112	C (mm^2)	9908739	9908739	9908739	9908739	9908739	9908739
	R (mm^2)	60319	60319	72985	122246	101938	154416
	β_{moment,dir_weak}	1.46	0.97	1.15	0.79	1.98	0.93
	$\beta_{moment,dir\_strong}$	2.27	2.39	1.31	1.81	2.13	1.79
	$\beta_{displacement,dir\_weak}$	7.53	7.44	7.45	6.77	7.23	6.56
	$\beta_{displacement,dir\_strong}$	7.69	7.69	7.60	7.34	7.49	7.07
	$\phi M_n/M_{u(weak\ dir.)}$	1.38	1.16	1.24	1.09	1.62	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.76	1.82	1.31	1.54	1.69	1.53
113	C (mm^2)	9908739	9908739	9908739	9908739	9908739	9908739
	R (mm^2)	48858	60319	60319	101938	72985	122246
	β_{moment,dir_weak}	1.11	1.23	0.62	0.89	0.83	0.79
	$\beta_{moment,dir\_strong}$	1.40	2.13	0.62	1.30	0.80	1.06
	$\beta_{displacement,dir\_weak}$	7.60	7.47	7.57	6.92	7.40	6.77
	$\beta_{displacement,dir\_strong}$	7.69	7.65	7.60	7.37	7.51	7.17
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.27	1.02	1.13	1.10	1.09
	$\phi M_n/M_{u(strong\ dir.)}$	1.35	1.69	1.02	1.30	1.09	1.20
114	C (mm^2)	9908739	9908739	9908739	9908739	9908739	9908739
	R (mm^2)	48858	60319	60319	101938	72985	122246
	β_{moment,dir_weak}	1.11	1.12	0.64	0.93	0.85	0.81
	$\beta_{moment,dir\_strong}$	1.37	1.88	0.66	1.27	0.84	1.04
	$\beta_{displacement,dir\_weak}$	7.60	7.45	7.57	6.95	7.41	6.80
	$\beta_{displacement,dir\_strong}$	7.68	7.60	7.60	7.35	7.50	7.14
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.22	1.02	1.14	1.11	1.10
	$\phi M_n/M_{u(strong\ dir.)}$	1.34	1.57	1.03	1.29	1.11	1.19
115	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	35387	35387	55292	93444	66903	93444
	β_{moment,dir_weak}	0.99	0.92	1.07	1.73	1.09	0.98
	$\beta_{moment,dir\_strong}$	1.60	1.99	1.39	2.71	1.41	1.72
	$\beta_{displacement,dir\_weak}$	7.74	7.74	7.60	7.24	7.46	7.08
	$\beta_{displacement,dir\_strong}$	7.68	7.71	7.52	7.29	7.38	7.12
	$\phi M_n/M_{u(weak\ dir.)}$	1.17	1.14	1.20	1.50	1.21	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.44	1.62	1.34	1.99	1.35	1.50
116	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	35387	35387	55292	93444	66903	93444
	β_{moment,dir_weak}	0.96	0.74	1.01	1.96	1.06	1.20
	$\beta_{moment,dir\_strong}$	1.29	1.38	1.27	2.44	1.28	1.51
	$\beta_{displacement,dir\_weak}$	7.72	7.70	7.58	7.21	7.43	7.06
	$\beta_{displacement,dir\_strong}$	7.64	7.63	7.48	7.17	7.32	7.02
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.07	1.18	1.61	1.20	1.26
	$\phi M_n/M_{u(strong\ dir.)}$	1.30	1.34	1.29	1.85	1.30	1.40

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
117	C (mm^2)	8658739	8658739	8658739	8658739	8658739	8658739
	R (mm^2)	35387	44787	55292	93444	66903	93444
	β_{moment,dir_weak}	0.78	1.38	0.89	1.74	0.94	1.02
	$\beta_{moment,dir\_strong}$	1.07	2.04	1.16	2.15	1.18	1.29
	$\beta_{displacement,dir\_weak}$	7.70	7.62	7.56	7.17	7.41	7.00
	$\beta_{displacement,dir\_strong}$	7.61	7.54	7.45	7.12	7.29	6.93
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.34	1.13	1.50	1.15	1.19
	$\phi M_n/M_{u(strong\ dir.)}$	1.20	1.65	1.24	1.70	1.25	1.30
118	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	74506	74506	125463	76454	157633
	β_{moment,dir_weak}	1.22	1.09	1.29	0.84	0.76	0.94
	$\beta_{moment,dir\_strong}$	2.02	3.09	1.42	1.50	0.74	1.36
	$\beta_{displacement,dir\_weak}$	7.42	7.04	7.45	6.58	7.34	6.35
	$\beta_{displacement,dir\_strong}$	7.80	7.83	7.75	7.59	7.70	7.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.27	1.21	1.30	1.11	1.07	1.15
	$\phi M_n/M_{u(strong\ dir.)}$	1.64	2.22	1.36	1.40	1.06	1.33
119	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	74506	74506	125463	76454	157633
	β_{moment,dir_weak}	0.90	0.78	1.11	0.62	0.59	0.70
	$\beta_{moment,dir\_strong}$	1.65	2.44	1.38	0.95	0.74	0.95
	$\beta_{displacement,dir\_weak}$	7.35	6.93	7.41	6.45	7.30	6.21
	$\beta_{displacement,dir\_strong}$	7.81	7.83	7.78	7.60	7.74	7.43
	$\phi M_n/M_{u(weak\ dir.)}$	1.13	1.08	1.22	1.02	1.00	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	1.46	1.85	1.34	1.15	1.07	1.16
120	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	74506	74506	125463	76454	157633
	β_{moment,dir_weak}	0.87	0.73	1.11	0.61	0.59	0.69
	$\beta_{moment,dir\_strong}$	1.45	2.07	1.28	0.73	0.64	0.76
	$\beta_{displacement,dir\_weak}$	7.34	6.90	7.41	6.43	7.29	6.19
	$\beta_{displacement,dir\_strong}$	7.80	7.82	7.78	7.57	7.73	7.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.12	1.06	1.22	1.01	1.00	1.05
	$\phi M_n/M_{u(strong\ dir.)}$	1.37	.166	1.30	1.06	1.02	1.07
121	C (mm^2)	11568584	11568584	11568584	11568584	11568584	11568584
	R (mm^2)	69115	83629	83629	176934	97691	176934
	β_{moment,dir_weak}	1.15	0.90	1.27	1.15	1.19	0.59
	$\beta_{moment,dir\_strong}$	2.20	3.16	1.69	2.43	1.53	1.47
	$\beta_{displacement,dir\_weak}$	7.49	7.16	7.50	6.69	7.36	6.48
	$\beta_{displacement,dir\_strong}$	7.65	7.63	7.62	7.16	7.53	6.97
	$\phi M_n/M_{u(weak\ dir.)}$	1.24	1.13	1.29	1.24	1.26	1.00
	$\phi M_n/M_{u(strong\ dir.)}$	1.73	2.26	1.48	1.85	1.41	1.38
122	C (mm^2)	11568584	11568584	11568584	11568584	11568584	11568584
	R (mm^2)	69115	83629	83629	176934	97691	176934
	β_{moment,dir_weak}	1.06	0.92	1.21	1.18	1.16	0.62
	$\beta_{moment,dir\_strong}$	1.44	2.23	1.19	1.48	1.05	0.65
	$\beta_{displacement,dir\_weak}$	7.45	7.11	7.47	6.63	7.33	6.39
	$\beta_{displacement,dir\_strong}$	7.56	7.53	7.55	6.92	7.45	6.67
	$\phi M_n/M_{u(weak\ dir.)}$	1.20	1.14	1.26	1.25	1.24	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.37	1.74	1.26	1.39	1.20	1.03

Table 4.1. *Continued*

Analysis number	Parameters	Spectrum Cases					
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
123	C (mm^2)	11568584	11568584	11568584	11568584	11568584	11568584
	R (mm^2)	69115	83629	83629	176934	97691	176934
	β_{moment,dir_weak}	1.08	0.97	1.26	1.21	1.21	0.68
	$\beta_{moment,dir\_strong}$	1.38	2.08	1.19	1.32	1.06	0.59
	$\beta_{displacement,dir\_weak}$	7.44	7.10	7.47	6.62	7.33	6.40
	$\beta_{displacement,dir\_strong}$	7.54	7.50	7.55	6.87	7.44	6.63
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.16	1.29	1.27	1.26	1.04
	$\phi M_n/M_{u(strong\ dir.)}$	1.34	1.67	1.26	1.31	1.20	1.00
124	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	61575	61575	125463	74506	157633
	β_{moment,dir_weak}	1.65	0.83	0.74	0.77	0.92	0.85
	$\beta_{moment,dir\_strong}$	1.94	1.93	0.69	1.15	0.90	1.04
	$\beta_{displacement,dir\_weak}$	7.61	7.52	7.63	6.95	7.50	6.76
	$\beta_{displacement,dir\_strong}$	7.52	7.51	7.51	6.84	7.40	6.37
	$\phi M_n/M_{u(weak\ dir.)}$	1.46	1.11	1.07	1.08	1.14	1.11
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	1.59	1.05	1.24	1.13	1.19
125	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	61575	61575	125463	74506	157633
	β_{moment,dir_weak}	1.76	0.79	0.86	0.97	1.10	1.01
	$\beta_{moment,dir\_strong}$	1.66	1.33	0.61	0.74	0.80	0.70
	$\beta_{displacement,dir\_weak}$	7.59	7.44	7.63	6.93	7.49	6.74
	$\beta_{displacement,dir\_strong}$	7.46	7.39	7.48	6.66	7.36	6.18
	$\phi M_n/M_{u(weak\ dir.)}$	1.51	1.09	1.11	1.16	1.22	1.18
	$\phi M_n/M_{u(strong\ dir.)}$	1.47	1.32	1.01	1.07	1.09	1.05
126	C (mm^2)	10068584	10068584	10068584	10068584	10068584	10068584
	R (mm^2)	61575	61575	61575	125463	74506	157633
	β_{moment,dir_weak}	1.66	0.78	0.82	0.92	1.06	0.94
	$\beta_{moment,dir\_strong}$	1.61	1.15	0.63	0.64	0.80	0.61
	$\beta_{displacement,dir\_weak}$	7.57	7.41	7.62	6.90	7.48	6.70
	$\beta_{displacement,dir\_strong}$	7.44	7.33	7.48	6.63	7.36	6.15
	$\phi M_n/M_{u(weak\ dir.)}$	1.47	1.08	1.10	1.14	1.20	1.15
	$\phi M_n/M_{u(strong\ dir.)}$	1.44	1.24	1.02	1.03	1.09	1.01
127	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	302397	199629	366737
	β_{moment,dir_weak}	1.05	1.22	1.45	0.67	0.86	0.61
	$\beta_{moment,dir\_strong}$	2.02	3.91	1.86	1.70	1.22	1.35
	$\beta_{displacement,dir\_weak}$	11.50	11.13	11.73	10.92	11.57	10.67
	$\beta_{displacement,dir\_strong}$	11.91	11.90	11.72	10.89	11.55	10.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.18	1.25	1.34	1.03	1.11	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.57	2.43	1.51	1.44	1.25	1.30
128	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	366737	208124	604794
	β_{moment,dir_weak}	0.66	0.85	1.13	0.69	0.74	0.98
	$\beta_{moment,dir\_strong}$	1.48	2.75	1.60	1.34	1.16	1.49
	$\beta_{displacement,dir\_weak}$	11.34	10.93	11.64	10.73	11.47	10.37
	$\beta_{displacement,dir\_strong}$	11.96	11.90	11.83	10.93	11.67	10.58
	$\phi M_n/M_{u(weak\ dir.)}$	1.03	1.10	1.21	1.04	1.05	1.15
	$\phi M_n/M_{u(strong\ dir.)}$	1.35	1.89	1.40	1.29	1.22	1.36

Table 4.1. *Continued*

Analysis number	Parameters	Spectrum Cases: Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
129	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	366737	208124	604794
	β_{moment,dir_weak}	0.64	0.81	1.13	0.68	0.74	1.25
	$\beta_{moment,dir\_strong}$	1.29	2.31	1.46	1.13	1.05	1.30
	$\beta_{displacement,dir\_weak}$	11.31	10.88	11.62	10.67	11.44	10.38
	$\beta_{displacement,dir\_strong}$	11.93	11.81	11.81	10.80	11.63	10.44
	$\phi M_n/M_{u(weak\ dir.)}$	1.02	1.08	1.21	1.03	1.06	1.26
	$\phi M_n/M_{u(strong\ dir.)}$	1.27	1.70	1.35	1.21	1.18	1.28
130	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	366737	199629	604794
	β_{moment,dir_weak}	0.90	1.13	1.30	0.85	0.74	1.07
	$\beta_{moment,dir\_strong}$	1.73	3.19	1.80	1.67	1.16	1.65
	$\beta_{displacement,dir\_weak}$	11.48	11.14	11.69	10.85	11.51	10.57
	$\beta_{displacement,dir\_strong}$	11.65	11.47	11.49	10.09	11.27	9.48
	$\phi M_n/M_{u(weak\ dir.)}$	1.12	1.21	1.28	1.10	1.05	1.19
	$\phi M_n/M_{u(strong\ dir.)}$	1.46	2.09	1.48	1.43	1.22	1.42
131	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	366737	199629	604794
	β_{moment,dir_weak}	0.80	1.01	1.28	0.78	0.72	1.00
	$\beta_{moment,dir\_strong}$	1.31	2.47	1.54	1.10	0.94	1.09
	$\beta_{displacement,dir\_weak}$	11.42	11.04	11.67	10.78	11.49	10.47
	$\beta_{displacement,dir\_strong}$	11.48	11.18	11.34	9.43	11.09	8.74
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.16	1.27	1.07	1.05	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.28	1.77	1.37	1.20	1.13	1.19
132	C (mm^2)	28000000	28000000	28000000	28000000	28000000	28000000
	R (mm^2)	142930	199629	199629	366737	199629	604794
	β_{moment,dir_weak}	0.80	0.97	1.29	0.78	0.73	1.02
	$\beta_{moment,dir\_strong}$	1.14	2.13	1.40	0.91	0.83	1.00
	$\beta_{displacement,dir\_weak}$	11.37	10.98	11.64	10.72	11.46	10.41
	$\beta_{displacement,dir\_strong}$	11.41	11.03	11.29	9.21	11.03	8.54
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.15	1.28	1.07	1.05	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.21	1.62	1.32	1.12	1.09	1.16
133	C (mm^2)	36000000	36000000	36000000	36000000	36000000	36000000
	R (mm^2)	182464	254846	254846	405341	254846	772078
	β_{moment,dir_weak}	0.80	1.50	1.20	0.62	0.66	0.79
	$\beta_{moment,dir\_strong}$	1.06	2.52	1.23	0.87	0.67	1.00
	$\beta_{displacement,dir\_weak}$	11.83	11.73	11.93	11.29	11.81	11.09
	$\beta_{displacement,dir\_strong}$	11.20	10.87	11.01	8.59	10.68	7.79
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.36	1.24	1.01	1.02	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.18	1.79	1.25	1.11	1.03	1.16
134	C (mm^2)	36000000	36000000	36000000	36000000	36000000	36000000
	R (mm^2)	182464	254846	254846	386039	254846	772078
	β_{moment,dir_weak}	1.02	1.63	1.44	0.73	0.85	1.01
	$\beta_{moment,dir\_strong}$	0.93	2.10	1.21	0.60	0.65	0.80
	$\beta_{displacement,dir\_weak}$	11.82	11.64	11.94	11.31	11.82	11.12
	$\beta_{displacement,dir\_strong}$	11.12	10.58	10.97	.826	10.63	7.59
	$\phi M_n/M_{u(weak\ dir.)}$	1.17	1.41	1.33	1.05	1.10	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.13	1.61	1.24	1.00	1.02	1.08

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
135	C (mm^2)	36000000	36000000	36000000	36000000	36000000	36000000
	R (mm^2)	182464	254846	254846	405341	254846	772078
	β_{moment,dir_weak}	1.04	1.74	1.45	0.80	0.86	0.97
	$\beta_{moment,dir\_strong}$	0.86	1.99	1.19	0.60	0.65	0.69
	$\beta_{displacement,dir\_weak}$	11.78	11.59	11.92	11.29	11.80	11.10
	$\beta_{displacement,dir\_strong}$	11.05	10.40	10.94	8.16	10.60	7.47
	$\phi M_n/M_{u(weak\ dir.)}$	1.17	1.46	1.34	1.08	1.11	1.15
	$\phi M_n/M_{u(strong\ dir.)}$	1.10	1.56	1.24	1.00	1.02	1.04
136	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	93444	102944	102944	205887	122246	279878
	β_{moment,dir_weak}	1.22	0.59	0.81	0.67	0.89	0.92
	$\beta_{moment,dir\_strong}$	1.95	2.04	1.16	1.25	1.24	1.36
	$\beta_{displacement,dir\_weak}$	7.16	6.79	7.26	6.09	7.01	5.76
	$\beta_{displacement,dir\_strong}$	7.82	7.83	7.81	7.57	7.79	7.38
	$\phi M_n/M_{u(weak\ dir.)}$	1.27	1.00	1.10	1.04	1.13	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.60	1.65	1.24	1.28	1.28	1.33
137	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	80701	93444	93444	205887	122246	279878
	β_{moment,dir_weak}	1.08	0.71	0.85	0.97	1.28	1.32
	$\beta_{moment,dir\_strong}$	1.16	1.38	0.73	0.79	1.16	1.12
	$\beta_{displacement,dir\_weak}$	7.31	6.98	7.36	6.31	7.14	6.05
	$\beta_{displacement,dir\_strong}$	7.82	7.82	7.80	7.52	7.79	7.35
	$\phi M_n/M_{u(weak\ dir.)}$	1.21	1.06	1.11	1.16	1.30	1.31
	$\phi M_n/M_{u(strong\ dir.)}$	1.24	1.34	1.06	1.09	1.24	1.23
138	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	80701	93444	93444	205887	122246	279878
	β_{moment,dir_weak}	1.05	0.73	0.79	0.93	1.22	1.26
	$\beta_{moment,dir\_strong}$	1.00	1.29	0.58	0.60	1.01	0.92
	$\beta_{displacement,dir\_weak}$	7.31	6.99	7.35	6.29	7.12	6.02
	$\beta_{displacement,dir\_strong}$	7.80	7.80	7.78	7.45	7.77	7.27
	$\phi M_n/M_{u(weak\ dir.)}$	1.20	1.06	1.09	1.14	1.27	1.29
	$\phi M_n/M_{u(strong\ dir.)}$	1.17	1.30	1.00	1.01	1.18	1.14
139	C (mm^2)	14568584	14568584	14568584	14568584	14568584	14568584
	R (mm^2)	79068	97691	97691	186585	114681	231623
	β_{moment,dir_weak}	0.72	0.59	0.65	0.71	0.66	0.74
	$\beta_{moment,dir\_strong}$	1.25	189	0.85	1.30	0.84	1.18
	$\beta_{displacement,dir\_weak}$	7.47	7.20	7.45	6.63	7.26	6.38
	$\beta_{displacement,dir\_strong}$	7.59	7.56	7.52	7.15	7.40	6.82
	$\phi M_n/M_{u(weak\ dir.)}$	1.06	1.00	1.03	1.05	1.03	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.28	1.57	1.11	1.30	1.11	1.25
140	C (mm^2)	14568584	14568584	14568584	14568584	14568584	14568584
	R (mm^2)	69944	84949	97691	167284	114681	205887
	β_{moment,dir_weak}	0.66	0.59	0.92	0.85	0.93	0.78
	$\beta_{moment,dir\_strong}$	0.84	1.21	0.94	0.92	0.93	0.72
	$\beta_{displacement,dir\_weak}$	7.55	7.34	7.50	6.79	7.32	6.55
	$\beta_{displacement,dir\_strong}$	7.57	7.51	7.52	7.14	7.39	6.81
	$\phi M_n/M_{u(weak\ dir.)}$	1.03	1.01	1.14	1.11	1.14	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.11	1.27	1.15	1.14	1.14	1.06

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
141	C (mm^2)	14568584	14568584	14568584	14568584	14568584	14568584
	R (mm^2)	79068	97691	97691	167284	114681	205887
	β_{moment,dir_weak}	0.95	0.98	0.83	0.73	0.83	0.65
	$\beta_{moment,dir\_strong}$	1.18	1.60	0.90	0.85	0.89	0.65
	$\beta_{displacement,dir\_weak}$	7.50	7.26	7.49	6.75	7.31	6.51
	$\beta_{displacement,dir\_strong}$	7.54	7.43	7.51	7.09	7.38	6.76
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.17	1.10	1.06	1.10	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.25	1.44	1.13	1.11	1.13	1.03
142	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	55292	66903	76027	122246	93444	141548
	β_{moment,dir_weak}	1.01	1.12	0.79	1.03	0.91	0.93
	$\beta_{moment,dir\_strong}$	1.19	2.02	0.93	1.36	1.02	1.10
	$\beta_{displacement,dir\_weak}$	7.74	7.69	7.63	7.32	7.49	7.13
	$\beta_{displacement,dir\_strong}$	7.63	7.62	7.48	7.26	7.35	7.04
	$\phi M_n/M_{u(weak\ dir.)}$	1.18	1.23	1.09	1.19	1.14	1.14
	$\phi M_n/M_{u(strong\ dir.)}$	1.26	1.64	1.15	1.33	1.18	1.22
143	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	55292	66903	76027	122246	93444	141548
	β_{moment,dir_weak}	1.07	1.15	0.76	1.11	0.88	0.99
	$\beta_{moment,dir\_strong}$	1.17	1.70	0.91	1.22	1.02	0.98
	$\beta_{displacement,dir\_weak}$	7.72	7.62	7.61	7.27	7.47	7.08
	$\beta_{displacement,dir\_strong}$	7.58	7.51	7.45	7.16	7.30	6.92
	$\phi M_n/M_{u(weak\ dir.)}$	1.20	1.24	1.08	1.22	1.12	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.25	1.48	1.14	1.27	1.18	1.17
144	C (mm^2)	13068584	13068584	13068584	13068584	13068584	13068584
	R (mm^2)	55292	66903	76027	122246	93444	141548
	β_{moment,dir_weak}	0.78	0.78	0.66	0.82	0.78	0.72
	$\beta_{moment,dir\_strong}$	0.94	1.24	0.83	1.00	0.95	0.81
	$\beta_{displacement,dir\_weak}$	7.68	7.56	7.60	7.19	7.46	6.99
	$\beta_{displacement,dir\_strong}$	7.53	7.41	7.43	7.07	7.28	6.83
	$\phi M_n/M_{u(weak\ dir.)}$	1.08	1.08	1.03	1.10	1.08	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.15	1.28	1.10	1.18	1.15	1.10
145	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	110433	125463	110433	212321	135114	279878
	β_{moment,dir_weak}	1.29	0.76	0.67	0.64	0.89	0.84
	$\beta_{moment,dir\_strong}$	2.35	2.62	0.97	1.32	1.21	1.35
	$\beta_{displacement,dir\_weak}$	7.28	6.92	7.42	6.38	7.22	6.12
	$\beta_{displacement,dir\_strong}$	7.81	7.83	7.78	7.61	7.74	7.44
	$\phi M_n/M_{u(weak\ dir.)}$	1.30	1.08	1.04	1.03	1.13	1.11
	$\phi M_n/M_{u(strong\ dir.)}$	1.80	1.95	1.16	1.31	1.27	1.33
146	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	110433	125463	110433	212321	135114	279878
	β_{moment,dir_weak}	1.25	0.71	0.70	0.65	0.93	0.86
	$\beta_{moment,dir\_strong}$	2.01	1.92	0.87	0.92	1.10	1.08
	$\beta_{displacement,dir\_weak}$	7.27	.689	7.43	6.38	7.23	6.13
	$\beta_{displacement,dir\_strong}$	7.81	7.80	7.78	7.58	7.74	7.42
	$\phi M_n/M_{u(weak\ dir.)}$	1.28	1.05	1.05	1.03	1.15	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.63	1.59	1.12	1.14	1.22	1.21

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
147	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	110433	125463	110433	212321	135114	279878
	β_{moment,dir_weak}	1.26	0.71	0.70	0.66	0.92	0.87
	$\beta_{moment,dir\_strong}$	1.70	1.54	0.65	0.59	0.86	0.76
	$\beta_{displacement,dir\_weak}$	7.26	6.87	7.42	6.36	7.22	6.10
	$\beta_{displacement,dir\_strong}$	7.78	7.76	7.76	7.50	7.71	7.33
	$\phi M_n/M_{u(weak\ dir.)}$	1.29	1.05	1.05	1.03	1.14	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.49	1.41	1.03	1.00	1.12	1.07
148	C (mm^2)	18371128	18371128	18371128	18371128	18371128	18371128
	R (mm^2)	123176	160850	123176	238057	160850	299180
	β_{moment,dir_weak}	1.45	1.52	0.79	0.62	1.26	0.66
	$\beta_{moment,dir\_strong}$	2.09	3.22	0.87	1.07	1.36	0.92
	$\beta_{displacement,dir\_weak}$	7.37	6.99	7.47	6.53	7.26	6.28
	$\beta_{displacement,dir\_strong}$	7.49	7.49	7.47	6.95	7.38	6.53
	$\phi M_n/M_{u(weak\ dir.)}$	1.37	1.40	1.09	1.02	1.29	1.03
	$\phi M_n/M_{u(strong\ dir.)}$	1.67	2.30	1.12	1.21	1.33	1.14
149	C (mm^2)	18371128	18371128	18371128	18371128	18371128	18371128
	R (mm^2)	123176	123176	123176	238057	160850	299180
	β_{moment,dir_weak}	1.58	0.59	0.95	0.80	1.42	0.87
	$\beta_{moment,dir\_strong}$	1.99	1.52	0.91	0.85	1.40	0.86
	$\beta_{displacement,dir\_weak}$	7.38	.713	7.49	6.58	7.30	6.35
	$\beta_{displacement,dir\_strong}$	7.47	7.41	7.48	6.88	7.39	6.48
	$\phi M_n/M_{u(weak\ dir.)}$	1.43	1.00	1.15	1.09	1.36	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.62	1.40	1.14	1.11	1.35	1.12
150	C (mm^2)	18371128	18371128	18371128	18371128	18371128	18371128
	R (mm^2)	123176	160850	123176	238057	160850	299180
	β_{moment,dir_weak}	1.56	1.67	0.93	0.78	1.41	0.86
	$\beta_{moment,dir\_strong}$	1.83	2.69	0.78	0.64	1.25	0.67
	$\beta_{displacement,dir\_weak}$	7.37	6.99	7.49	6.56	7.29	6.33
	$\beta_{displacement,dir\_strong}$	7.44	7.37	7.45	6.82	7.36	6.41
	$\phi M_n/M_{u(weak\ dir.)}$	1.42	1.47	1.15	1.08	1.35	1.12
	$\phi M_n/M_{u(strong\ dir.)}$	1.54	1.99	1.08	1.03	1.28	1.04
151	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	79068	110433	110433	212321	125463	279878
	β_{moment,dir_weak}	0.84	1.35	1.29	1.16	1.15	1.27
	$\beta_{moment,dir\_strong}$	0.72	2.10	0.96	0.92	0.80	0.89
	$\beta_{displacement,dir\_weak}$	7.65	7.50	7.62	7.02	7.52	6.81
	$\beta_{displacement,dir\_strong}$	7.40	7.37	7.39	6.54	7.26	5.90
	$\phi M_n/M_{u(weak\ dir.)}$	1.11	1.33	1.30	1.24	1.24	1.29
	$\phi M_n/M_{u(strong\ dir.)}$	1.06	1.67	1.16	1.14	1.09	1.13
152	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	79068	110433	110433	193019	110433	225189
	β_{moment,dir_weak}	0.95	1.64	1.37	1.00	0.74	0.78
	$\beta_{moment,dir\_strong}$	1.13	2.26	1.55	0.88	0.81	0.68
	$\beta_{displacement,dir\_weak}$	7.63	7.46	7.61	6.97	7.53	6.76
	$\beta_{displacement,dir\_strong}$	7.48	7.37	7.50	6.79	7.39	6.46
	$\phi M_n/M_{u(weak\ dir.)}$	1.15	1.46	1.34	1.17	1.07	1.08
	$\phi M_n/M_{u(strong\ dir.)}$	1.23	1.76	1.42	1.13	1.10	1.04

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
153	C (mm^2)	16621128	16621128	16621128	16621128	16621128	16621128
	R (mm^2)	79068	110433	110433	167284	110433	167284
	β_{moment,dir_weak}	1.21	1.80	1.40	1.19	0.75	0.63
	$\beta_{moment,dir\_strong}$	1.63	2.51	1.63	1.48	0.92	0.85
	$\beta_{displacement,dir\_weak}$	7.63	7.43	7.62	7.02	7.53	6.82
	$\beta_{displacement,dir\_strong}$	7.48	7.34	7.49	6.96	7.37	6.75
	$\phi M_n/M_{u(weak\ dir.)}$	1.26	1.53	1.35	1.25	1.07	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.45	1.89	1.45	1.39	1.14	1.11
154	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	250925	206001	386039	250925	540454
	β_{moment,dir_weak}	1.16	1.38	0.97	0.63	1.17	0.65
	$\beta_{moment,dir\_strong}$	2.21	3.73	1.45	1.31	1.75	1.16
	$\beta_{displacement,dir\_weak}$	11.07	10.56	11.39	10.21	11.22	9.84
	$\beta_{displacement,dir\_strong}$	11.90	11.79	11.85	10.81	11.61	10.45
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.31	1.15	1.01	1.23	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.65	2.34	1.34	1.28	1.46	1.22
155	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	250925	206001	408558	250925	598360
	β_{moment,dir_weak}	1.00	1.20	0.90	0.65	1.10	0.75
	$\beta_{moment,dir\_strong}$	1.82	2.79	1.23	1.09	1.51	1.10
	$\beta_{displacement,dir\_weak}$	11.00	10.44	11.37	10.18	11.20	9.67
	$\beta_{displacement,dir\_strong}$	11.84	11.61	11.81	10.66	11.56	10.30
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.24	1.12	1.02	1.20	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.49	1.91	1.25	1.20	1.37	1.20
156	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	250925	206001	408558	250925	598360
	β_{moment,dir_weak}	1.01	1.19	0.90	0.65	1.10	0.75
	$\beta_{moment,dir\_strong}$	1.42	2.20	0.92	0.78	1.19	0.79
	$\beta_{displacement,dir\_weak}$	10.98	10.40	11.34	10.09	11.17	9.71
	$\beta_{displacement,dir\_strong}$	11.71	11.35	11.70	10.30	11.40	9.91
	$\phi M_n/M_{u(weak\ dir.)}$	1.16	1.23	1.12	1.02	1.20	1.06
	$\phi M_n/M_{u(strong\ dir.)}$	1.33	1.65	1.13	1.07	1.23	1.08
157	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	206001	206001	386039	250925	540454
	β_{moment,dir_weak}	1.21	0.69	1.03	0.66	1.27	0.65
	$\beta_{moment,dir\_strong}$	2.10	2.28	1.45	1.13	1.75	0.91
	$\beta_{displacement,dir\_weak}$	11.19	10.63	11.46	10.34	11.30	9.98
	$\beta_{displacement,dir\_strong}$	11.51	11.37	11.49	9.66	11.12	9.07
	$\phi M_n/M_{u(weak\ dir.)}$	1.24	1.04	1.17	1.03	1.27	1.02
	$\phi M_n/M_{u(strong\ dir.)}$	1.61	1.69	1.34	1.21	1.46	1.12
158	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	206001	206001	386039	250925	540454
	β_{moment,dir_weak}	1.15	0.65	1.00	0.62	1.24	0.62
	$\beta_{moment,dir\_strong}$	1.71	1.59	1.19	0.84	1.49	0.72
	$\beta_{displacement,dir\_weak}$	11.09	10.50	11.40	10.22	11.23	9.76
	$\beta_{displacement,dir\_strong}$	11.39	11.08	11.39	.931	10.99	8.74
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.02	1.16	1.01	1.26	1.01
	$\phi M_n/M_{u(strong\ dir.)}$	1.45	1.39	1.24	1.09	1.35	1.05

Table 4.1. *Continued*

		Spectrum Cases					
Analysis number	Parameters	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
159	C (mm^2)	29500000	29500000	29500000	29500000	29500000	29500000
	R (mm^2)	180516	206001	206001	408558	250925	598360
	β_{moment,dir_weak}	1.16	0.66	1.00	0.72	1.24	0.77
	$\beta_{moment,dir\_strong}$	1.36	1.16	0.91	0.67	1.18	0.63
	$\beta_{displacement,dir\_weak}$	11.03	10.40	11.36	10.11	11.18	9.72
	$\beta_{displacement,dir\_strong}$	11.20	10.73	11.25	8.88	10.79	8.24
	$\phi M_n/M_{u(weak\ dir.)}$	1.22	1.02	1.16	1.05	1.26	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.30	1.22	1.12	1.03	1.23	1.01
160	C (mm^2)	37500000	37500000	37500000	37500000	37500000	37500000
	R (mm^2)	234671	261217	261217	791380	355477	965097
	β_{moment,dir_weak}	1.10	0.73	0.88	0.93	1.60	0.77
	$\beta_{moment,dir\_strong}$	1.14	1.36	0.70	0.82	1.37	0.62
	$\beta_{displacement,dir\_weak}$	11.67	11.42	11.78	11.03	11.69	10.79
	$\beta_{displacement,dir\_strong}$	10.90	10.65	10.87	7.81	10.16	7.05
	$\phi M_n/M_{u(weak\ dir.)}$	1.20	1.05	1.11	1.13	1.40	1.07
	$\phi M_n/M_{u(strong\ dir.)}$	1.22	1.30	1.04	1.09	1.31	1.01
161	C (mm^2)	37500000	37500000	37500000	37500000	37500000	37500000
	R (mm^2)	234671	234671	261217	791380	355477	965097
	β_{moment,dir_weak}	1.39	0.68	1.11	1.18	1.87	1.03
	$\beta_{moment,dir\_strong}$	1.17	0.78	0.84	0.78	1.53	0.67
	$\beta_{displacement,dir\_weak}$	11.64	11.36	11.77	11.01	11.69	10.79
	$\beta_{displacement,dir\_strong}$	11.13	10.83	11.17	8.64	10.60	8.05
	$\phi M_n/M_{u(weak\ dir.)}$	1.32	1.03	1.20	1.23	1.51	1.17
	$\phi M_n/M_{u(strong\ dir.)}$	1.23	1.07	1.09	1.07	1.37	1.03
162	C (mm^2)	37500000	37500000	37500000	37500000	37500000	37500000
	R (mm^2)	234671	234671	261217	791380	355477	887889
	β_{moment,dir_weak}	1.34	0.73	.099	1.06	1.71	1.01
	$\beta_{moment,dir\_strong}$	0.98	0.63	0.66	0.61	1.31	0.64
	$\beta_{displacement,dir\_weak}$	11.53	11.19	11.69	10.84	11.60	10.57
	$\beta_{displacement,dir\_strong}$	11.03	10.61	11.12	8.49	10.52	7.87
	$\phi M_n/M_{u(weak\ dir.)}$	1.29	1.05	1.15	1.18	1.44	1.16
	$\phi M_n/M_{u(strong\ dir.)}$	1.15	1.01	1.02	1.01	1.28	1.02

4.2. Graphical Representations and Comments

The results are given in the table above in detail. Columns have been investigated based on moment reliability and moment carrying capacity to demand ratio in both weak and strong directions. Graphical expressions of these parameters are shown below:

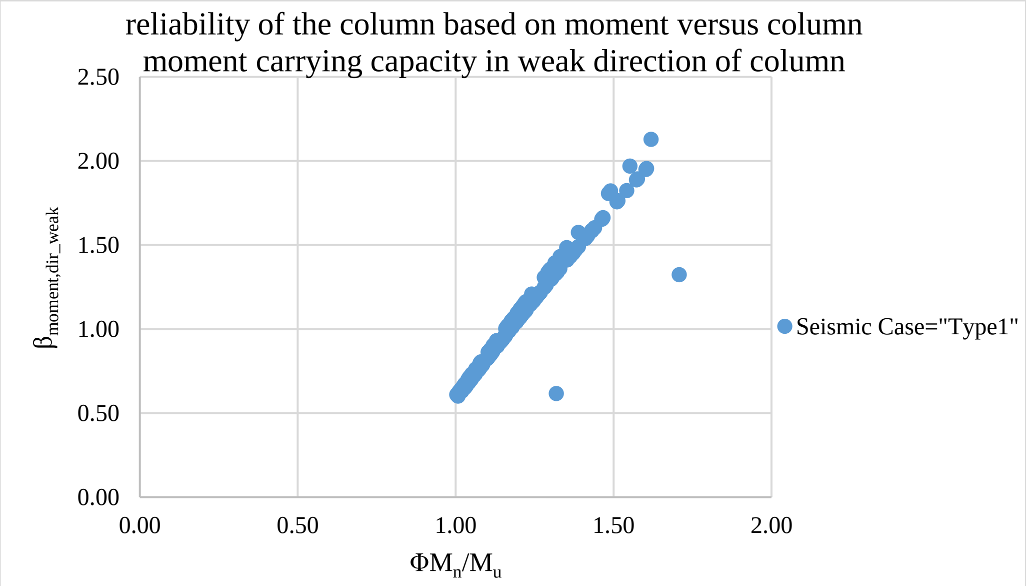


Figure 4.1. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case "Type 1"

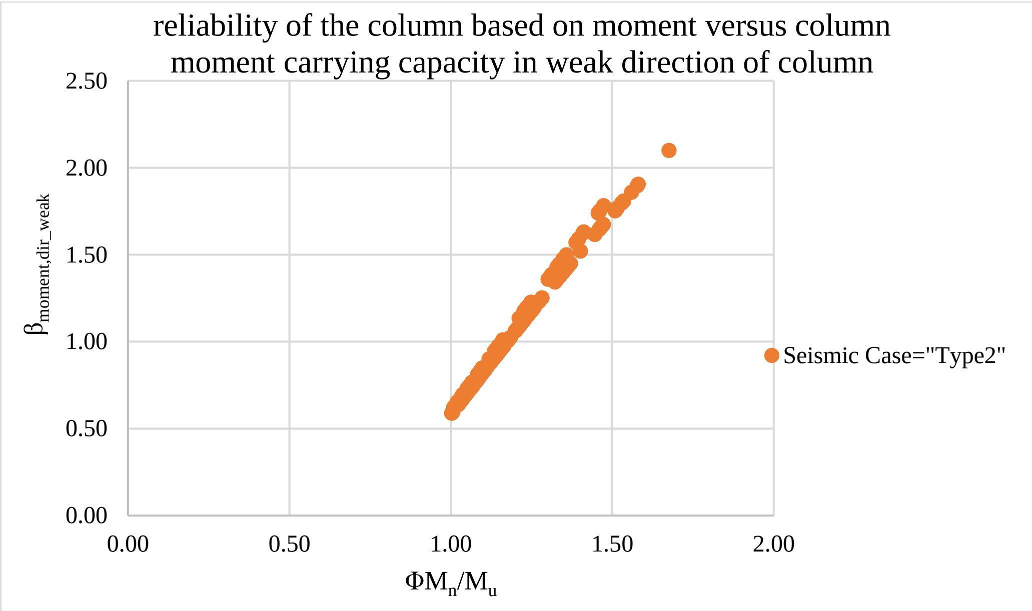


Figure 4.2. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case “Type 2”

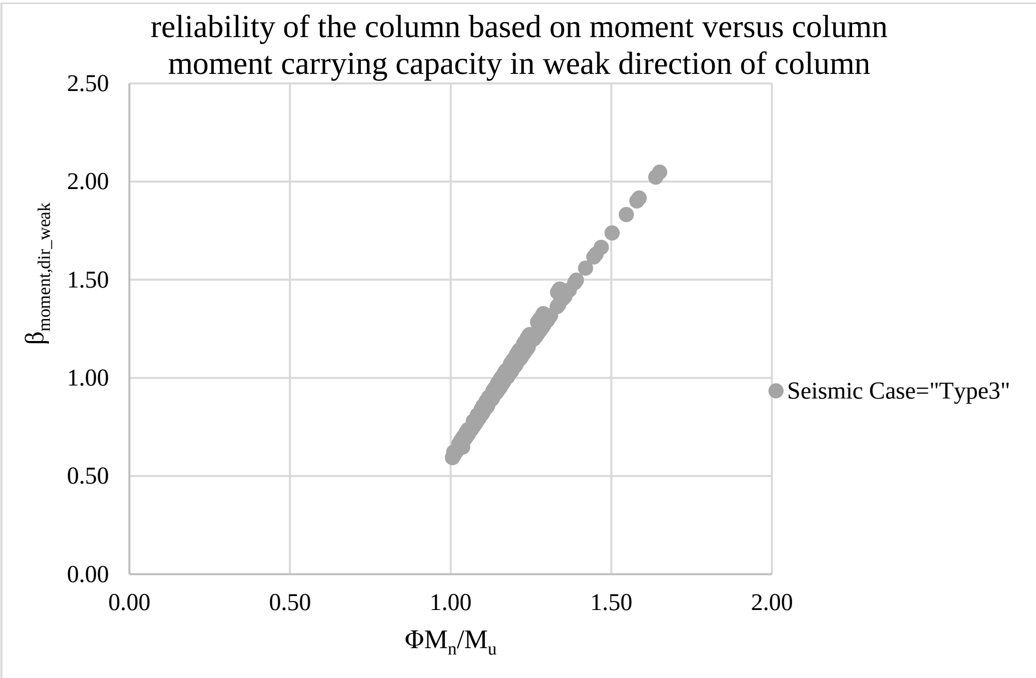


Figure 4.3. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case “Type 3”

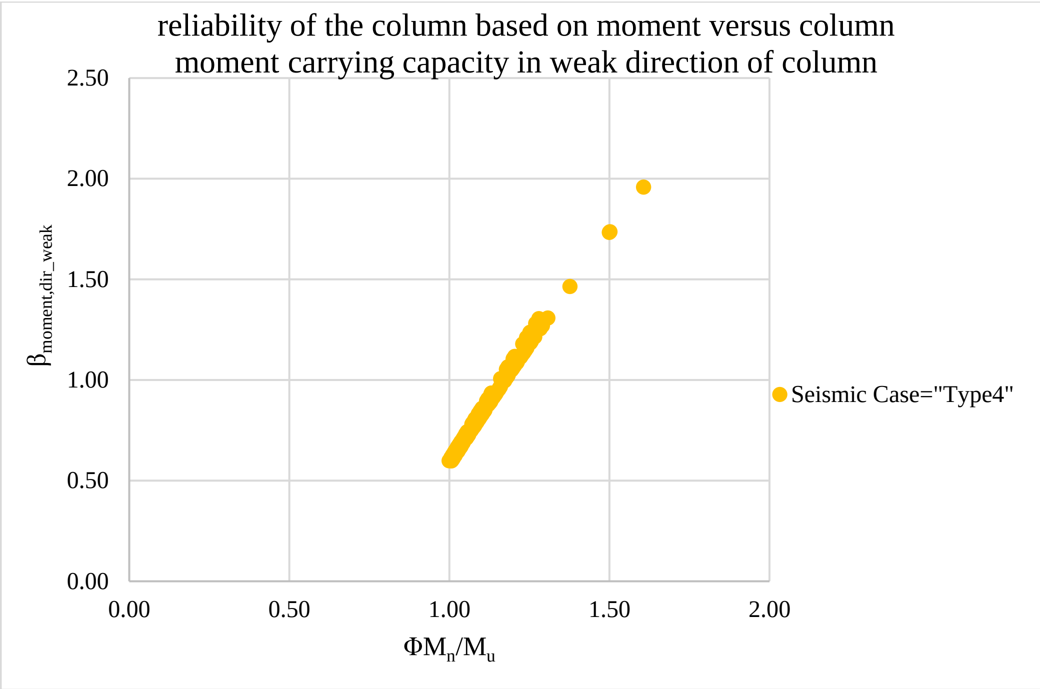


Figure 4.4. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case “Type 4”

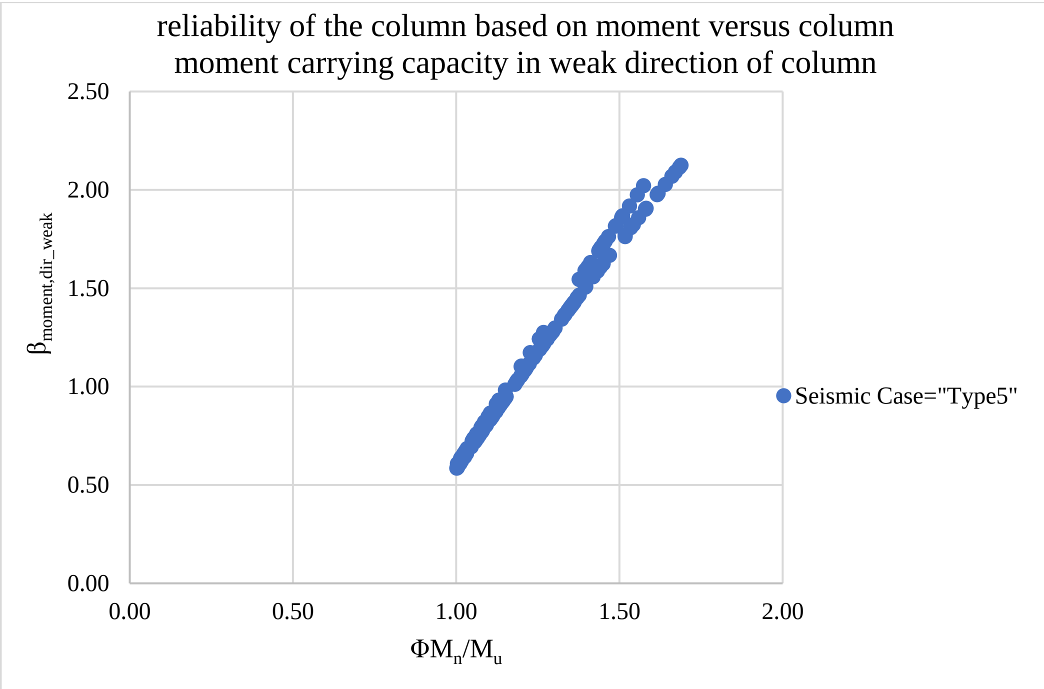


Figure 4.5. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case “Type 5”

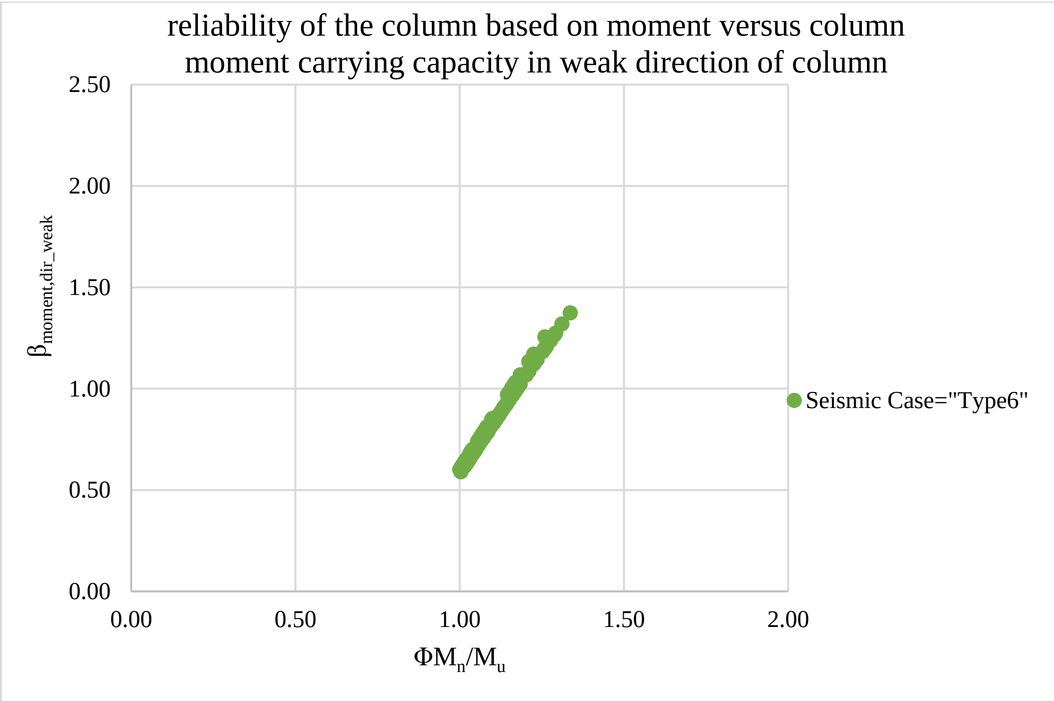


Figure 4.6. Reliability based on Moment versus Column Moment Carrying Capacity in Weak Direction of Column for Seismic Case “Type 6”

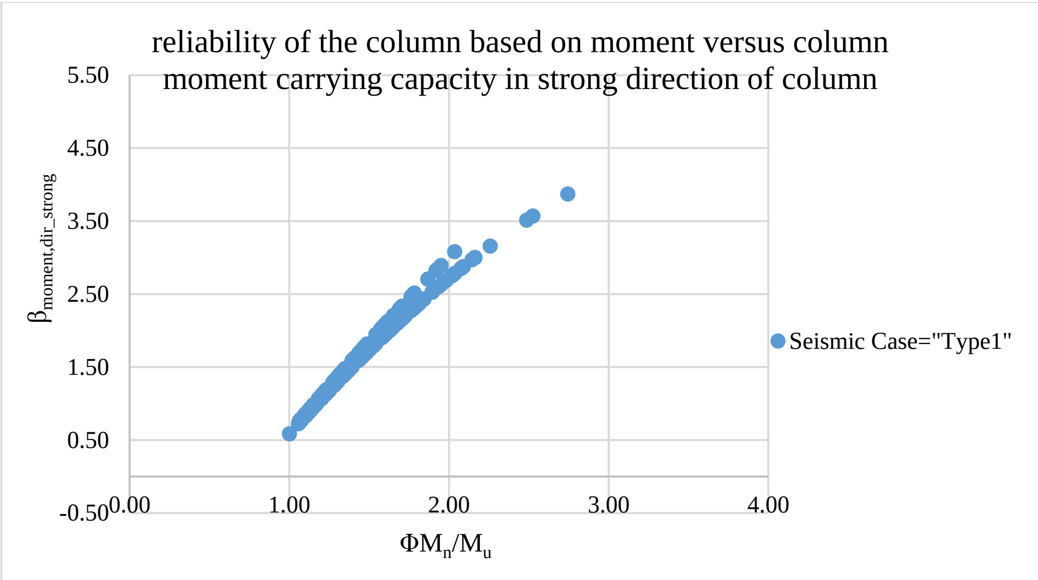


Figure 4.7. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case “Type 1”

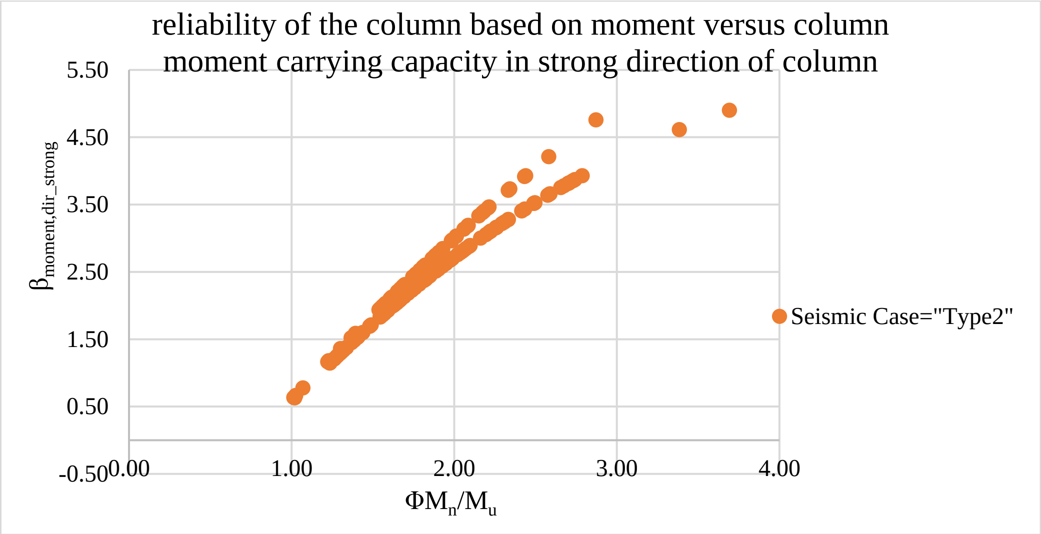


Figure 4.8. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case "Type 2"

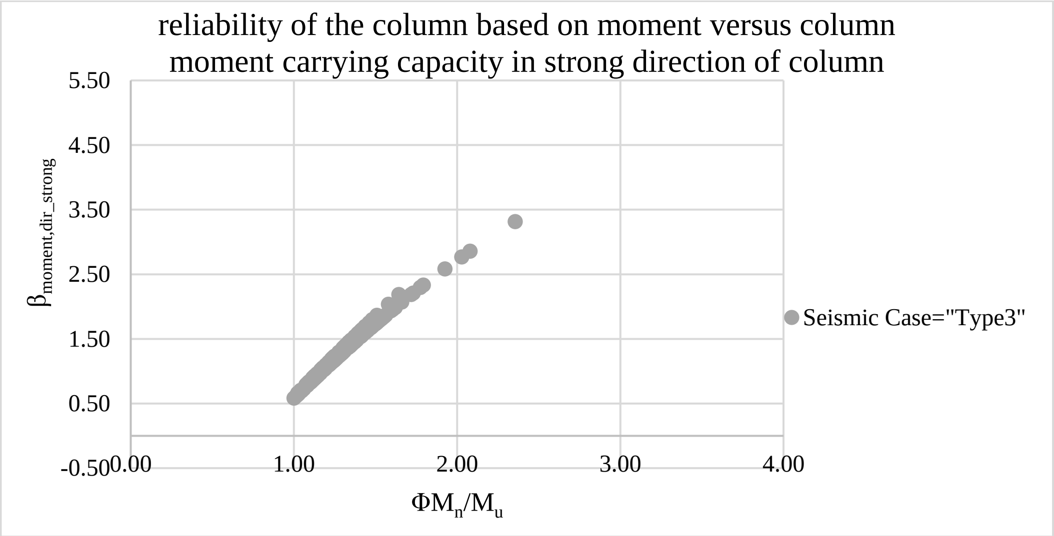


Figure 4.9. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case "Type 3"

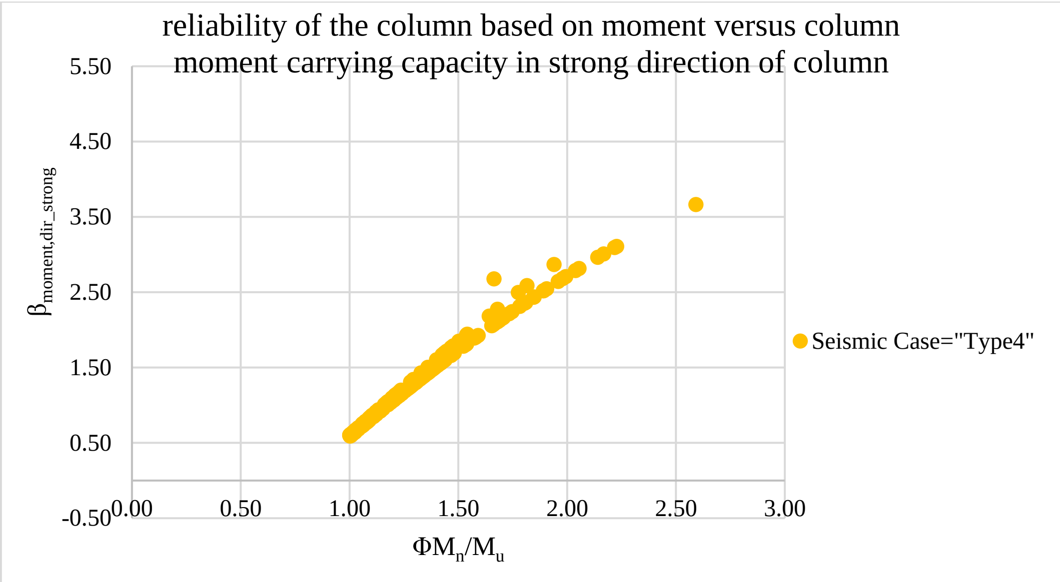


Figure 4.10. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case "Type 4"

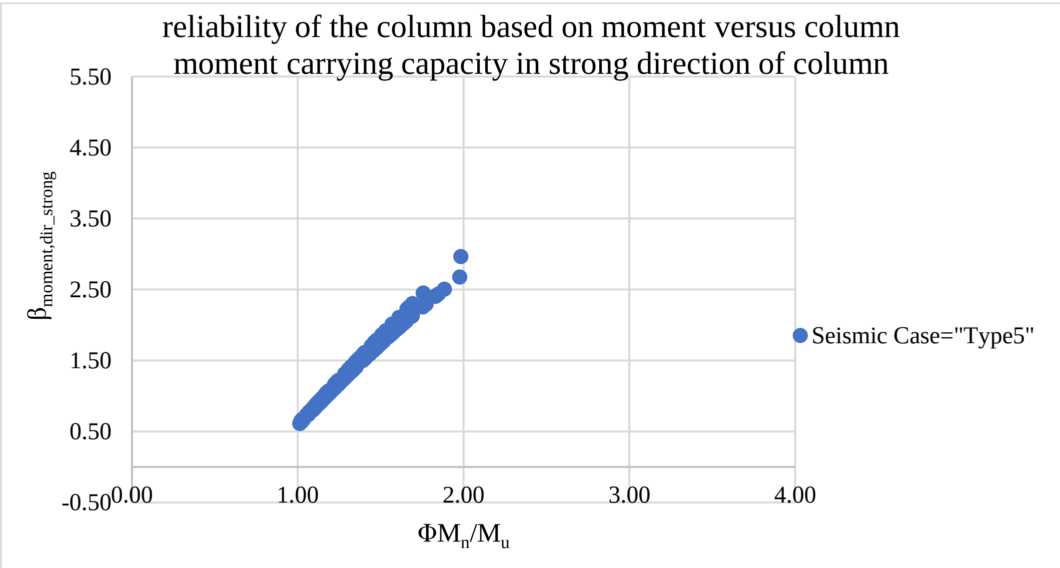


Figure 4.11. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case "Type 5"

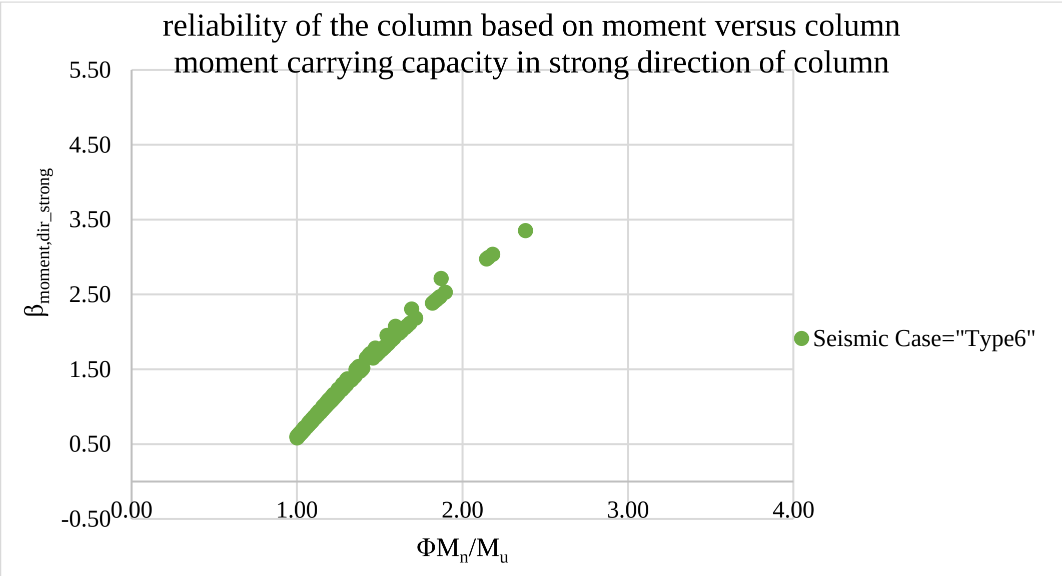


Figure 4.12. Reliability based on Moment versus Column Moment Carrying Capacity in Strong Direction of Column for Seismic Case "Type 6"

From the graphical expressions above, it can be deduced that the relationship between moment reliability and moment carrying capacity to demand ratio of columns is linear since moment reliability is directly related with ΦM_n and M_u. However, the results tend to have two slightly different slopes. Reliability can be different for the same $\Phi M_n/M_u$ ratio since coefficient of variation, ΦM_n and M_u in computation can differ from one to other solution.

Also, M_n, nominal moment capacity does not represent total collapse state and therefore, reliability is very low when design moments are close to nominal capacities. In pushover analysis, the structure has proven to have more displacement capacity to failure. Therefore, the collapse reliabilities shall be determined from pushover analysis.

The ratio of nominal moment capacity limit state reliability to displacement capacity reliability (collapse) is about 1/7.

Columns are also investigated in the aspects of displacement reliability and nominal displacement to elastic dynamic displacement ratio (Δ_p/Δ_d). These parameters are compared to each other in weak and strong directions as shown in the figures below:

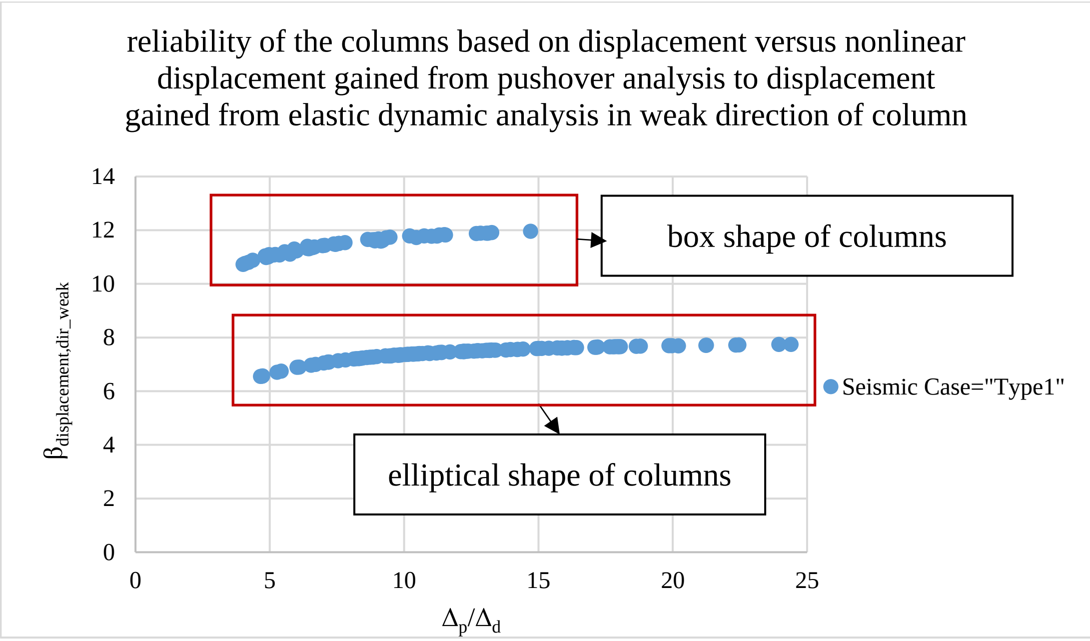


Figure 4.13. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case "Type 1"

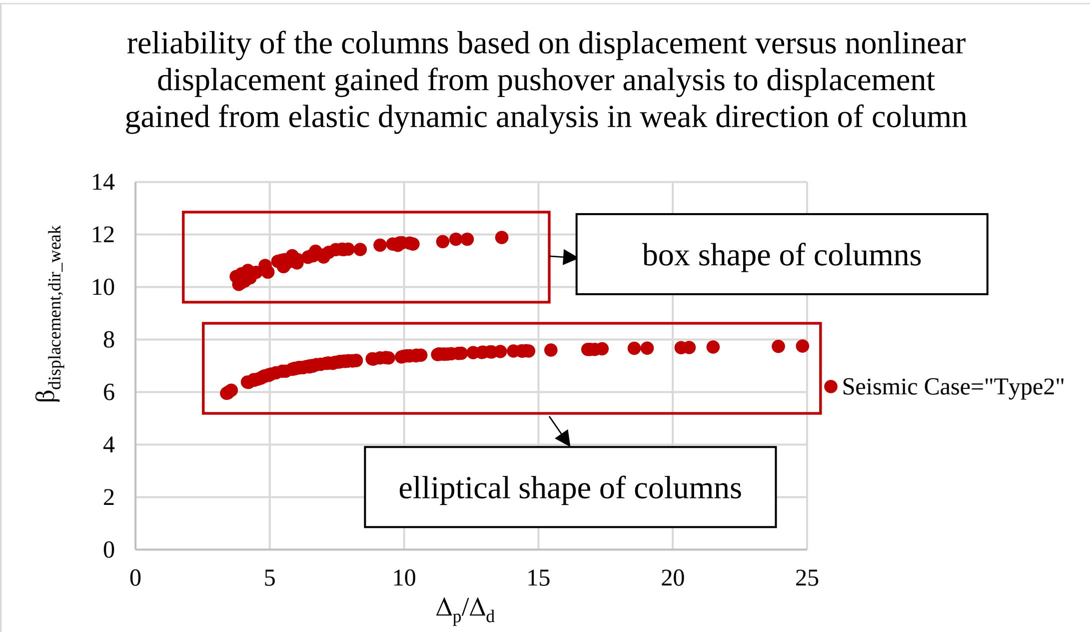


Figure 4.14. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case "Type 2"

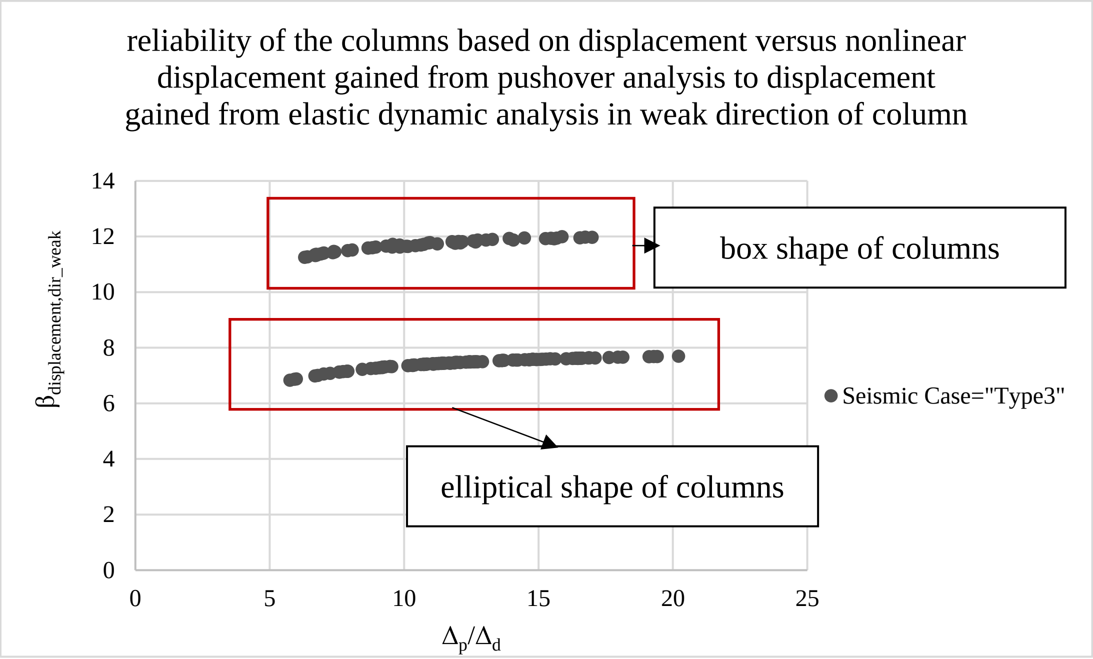


Figure 4.15. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case “Type 3”

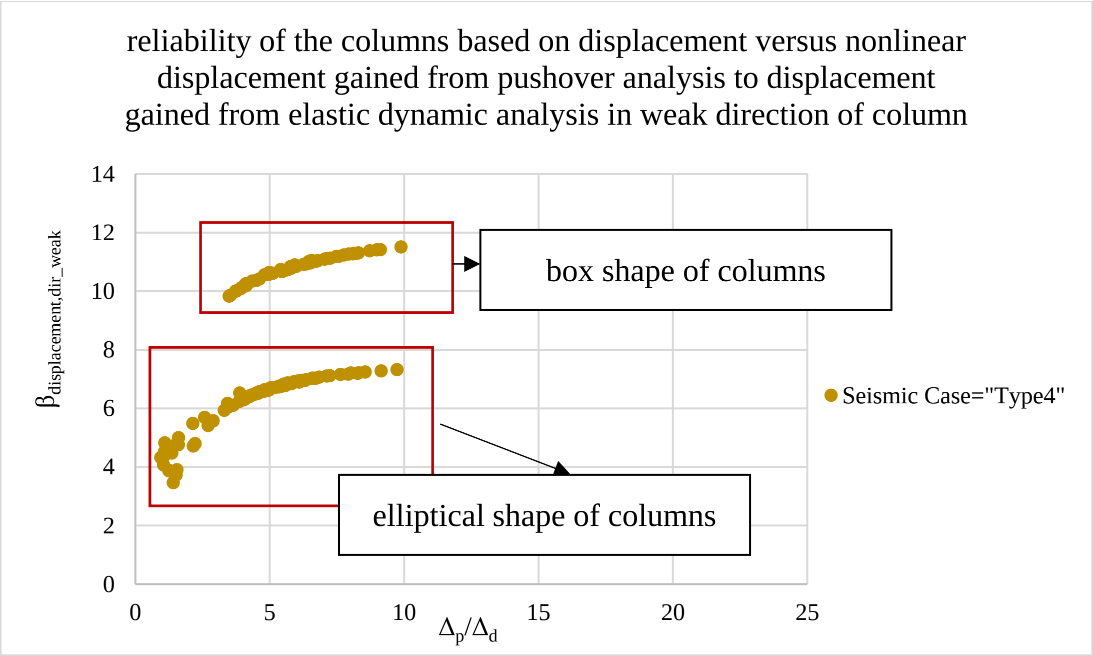


Figure 4.16. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case “Type 4”

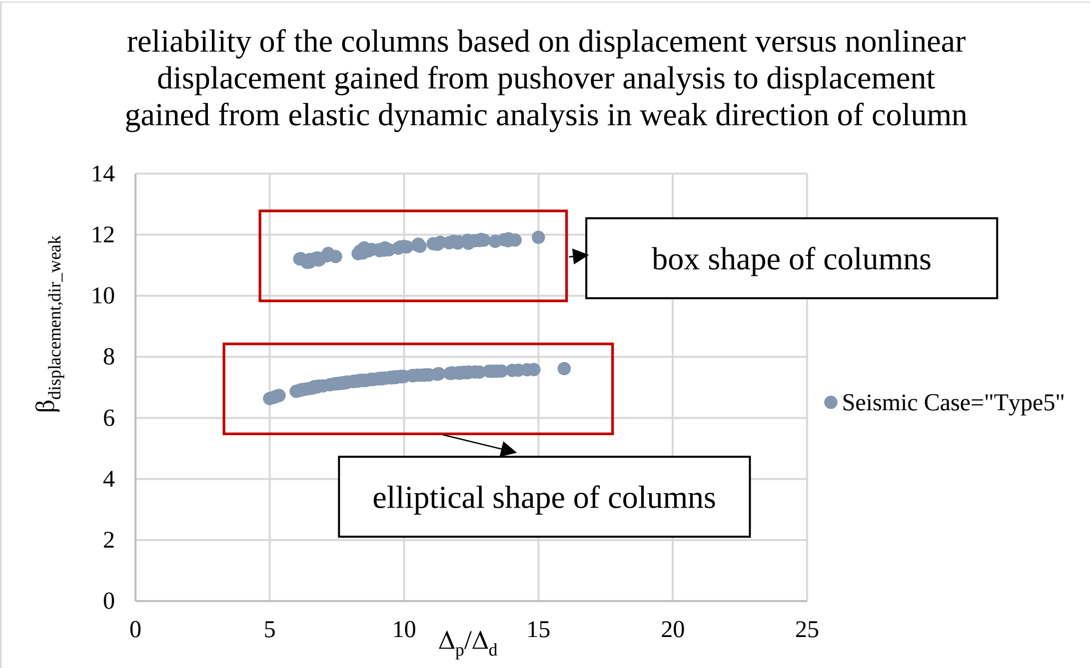


Figure 4.17. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case “Type 5”

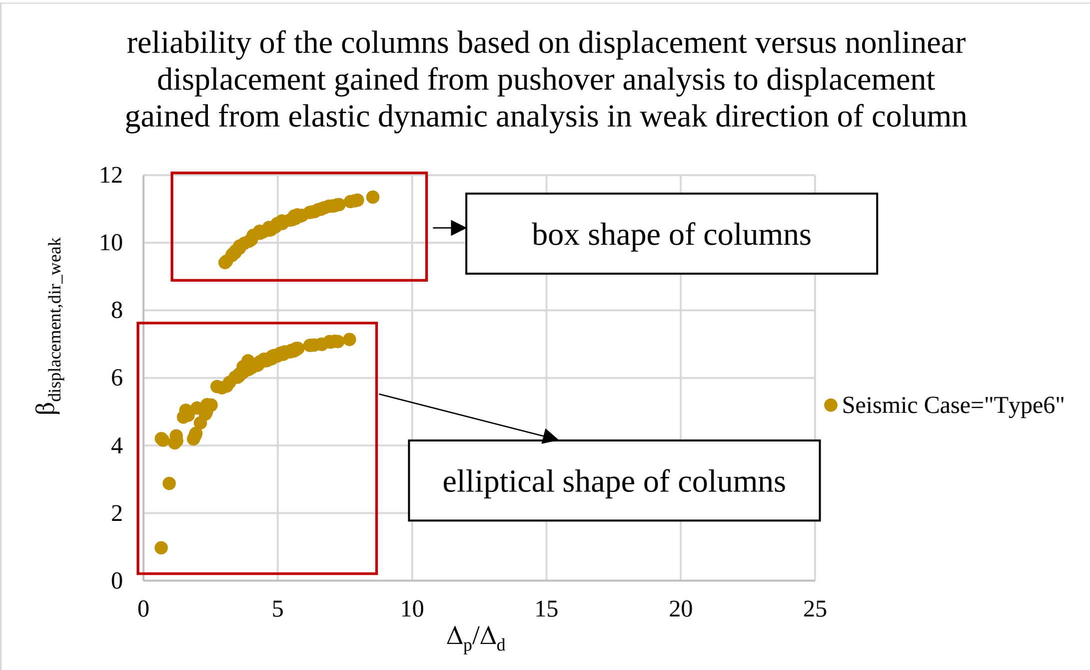


Figure 4.18. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column for Seismic Case “Type 6”

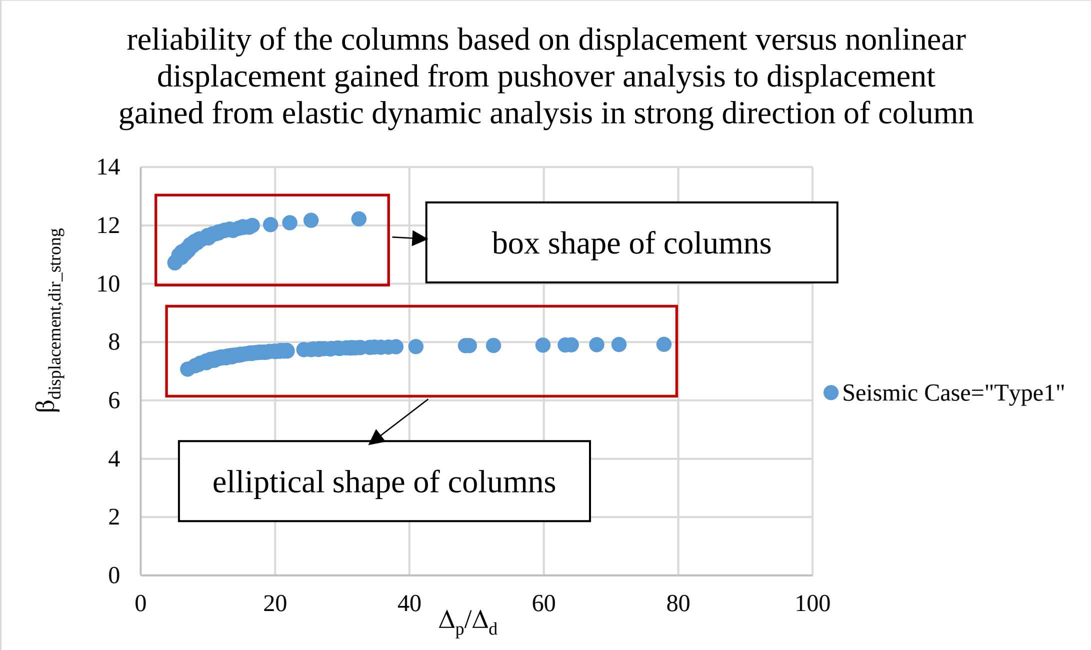


Figure 4.19. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case "Type 1"

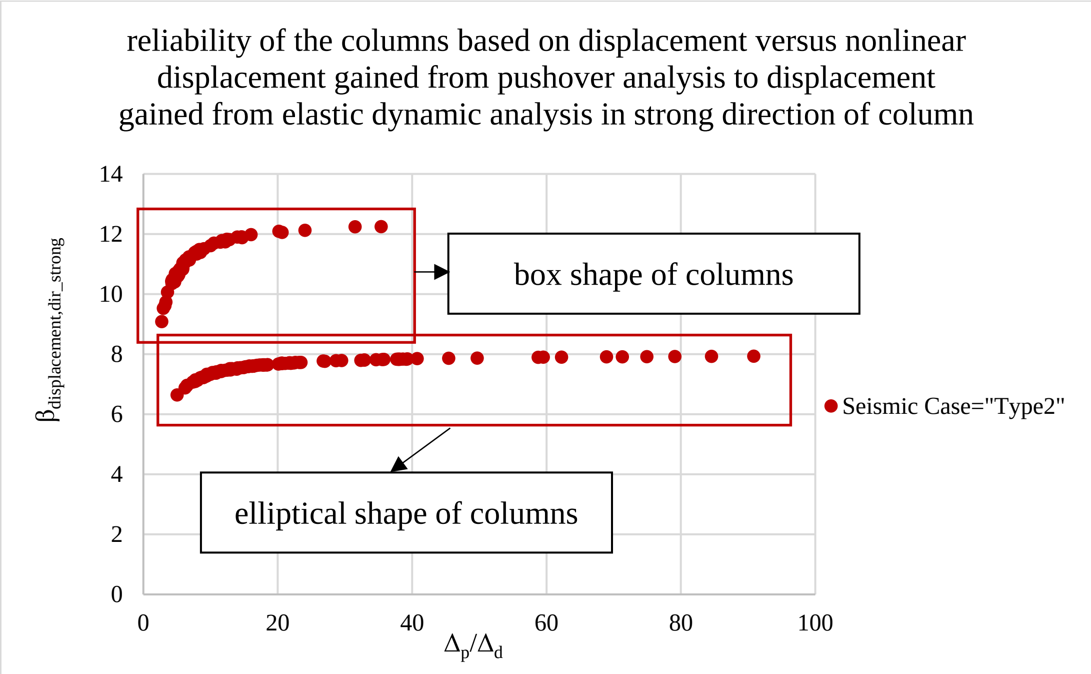


Figure 4.20. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case "Type 2"

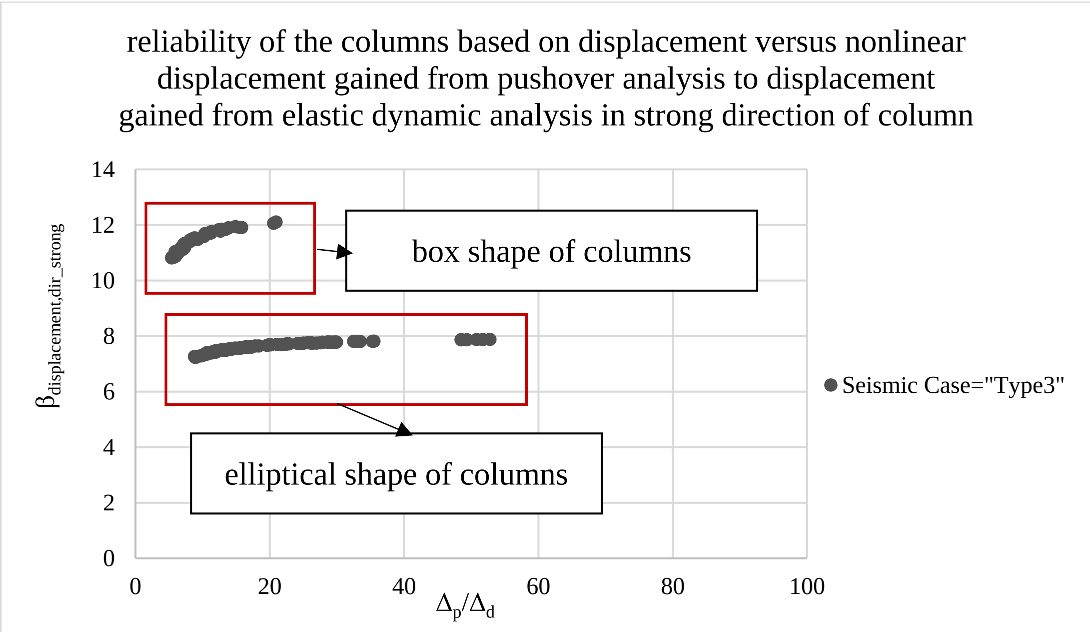


Figure 4.21. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case “Type 3”

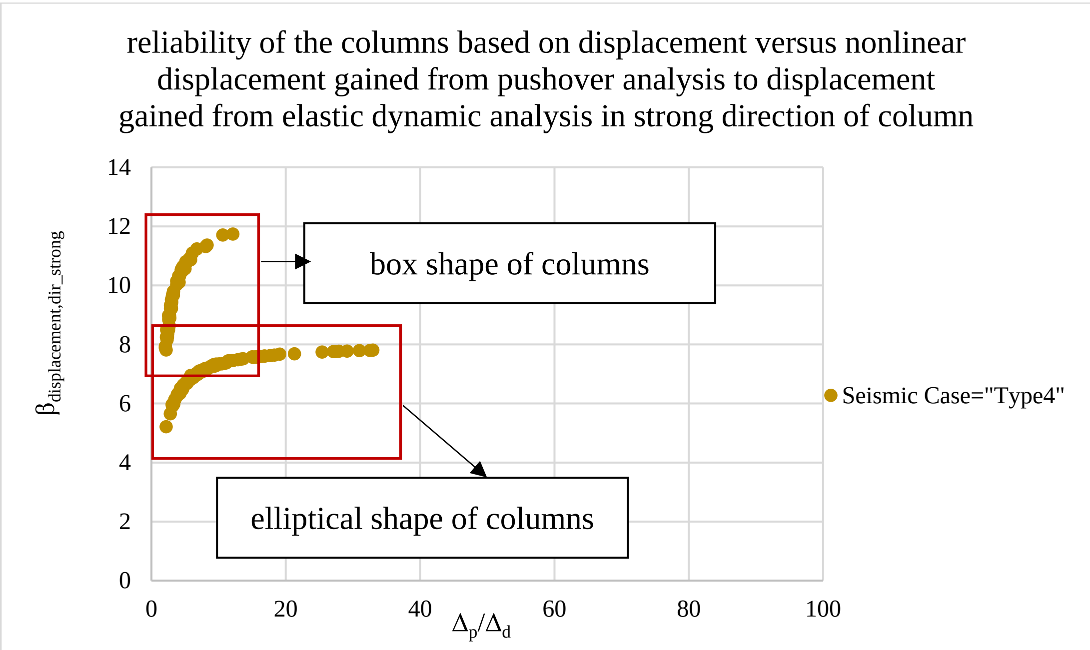


Figure 4.22. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case “Type 4”

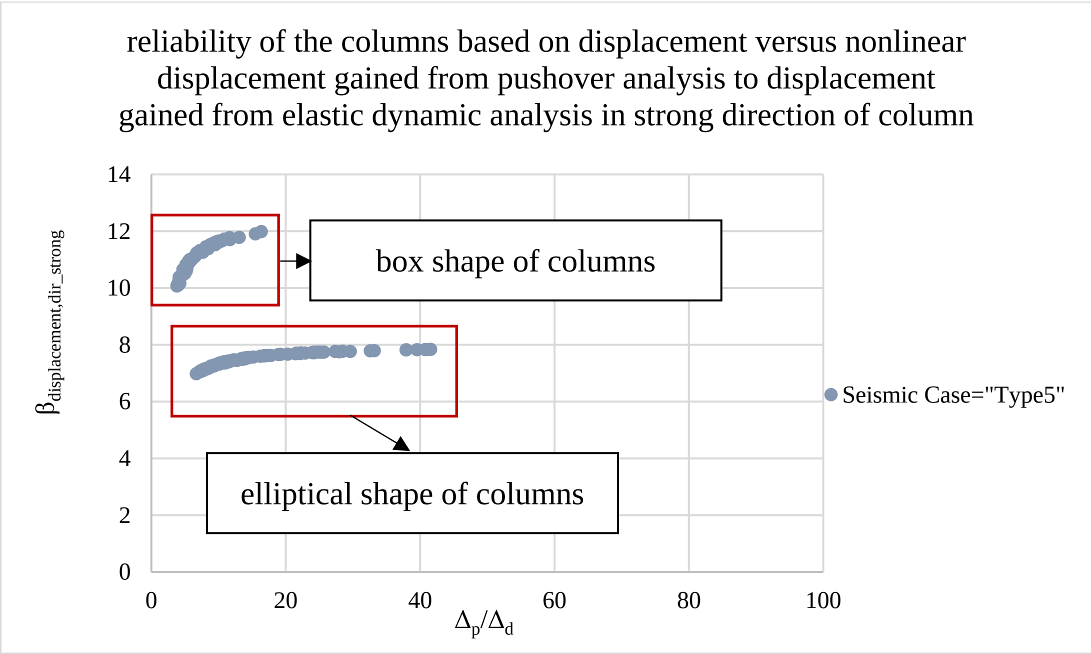


Figure 4.23. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case "Type 5"

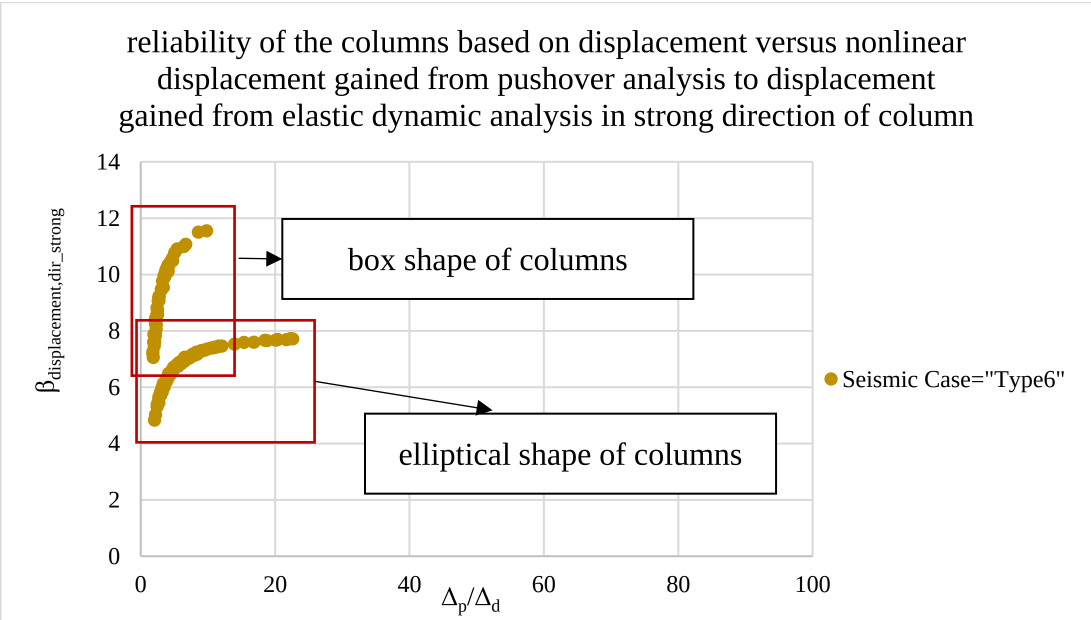


Figure 4.24. Reliability based on Displacement versus Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column for Seismic Case "Type 6"

From the figures about the relationship between displacement reliability and Δ_p/Δ_d ratio, it can be deduced that, box column displacement reliabilities are higher than elliptical column's since it is more rigid when compared to elliptical ones.

Column moment reliabilities are also compared with the cross sectional areas of them in terms of reinforcement ratio amounts in the following figures:

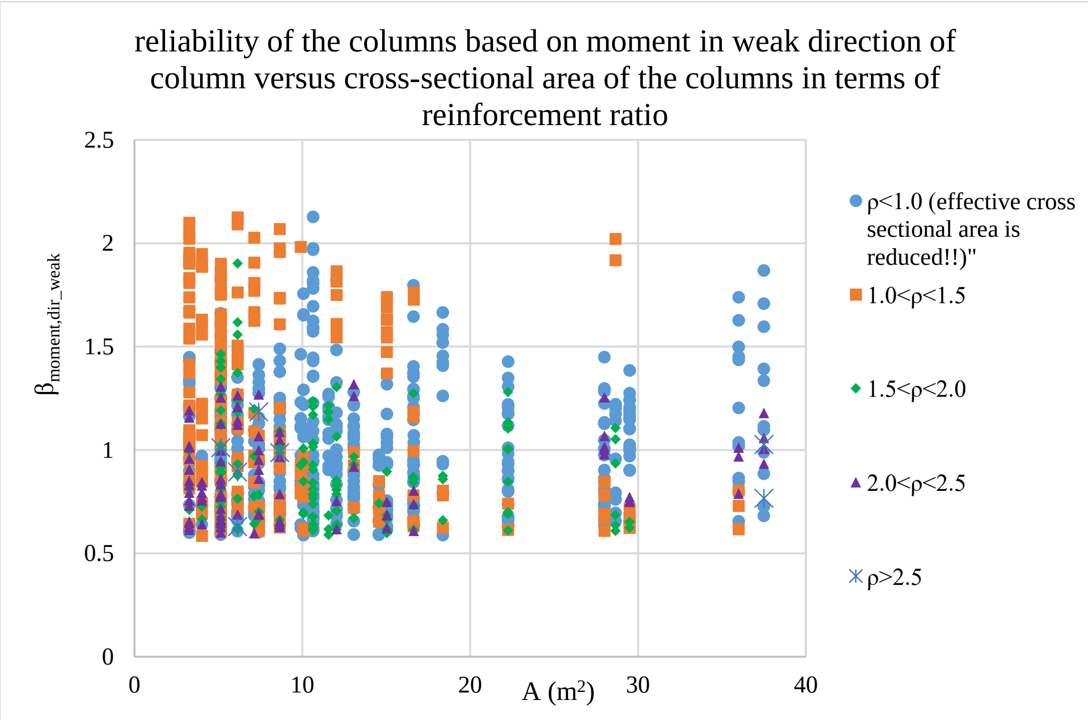


Figure 4.25. Reliability based on Moment in Weak Direction of Column versus Cross Sectional Area of Columns in terms of Reinforcement Ratio

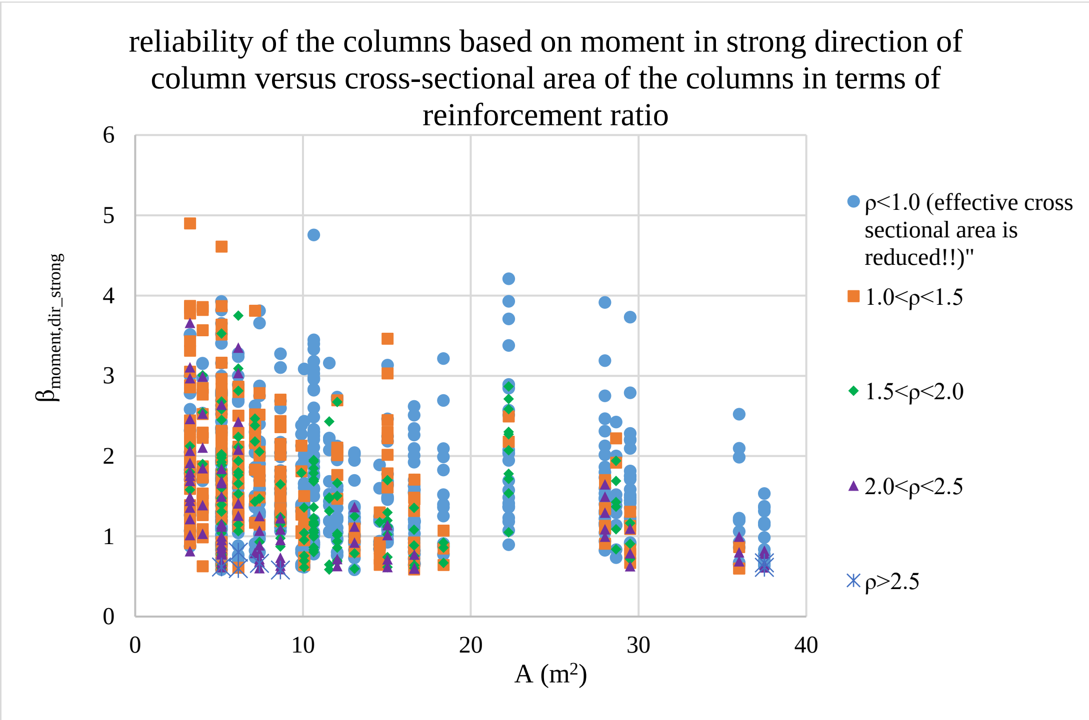


Figure 4.26. Reliability based on Moment in Strong Direction of Column versus Cross Sectional Area of Columns in terms of Reinforcement Ratio

Quantity and reliability relationship cannot be directly understood from the figure above because all of the models have their own forces and quantities. Both quantity and the resultant moments are changing for one hundred and sixty two bridges with six different seismic cases.

In fact, the damage states of columns are determined based on nominal displacement to elastic dynamic displacement ratio (Δ_p/Δ_d). In order to see the relationship between moment carrying capacity to demand ratio and Δ_p/Δ_d, the related figures are shown below:

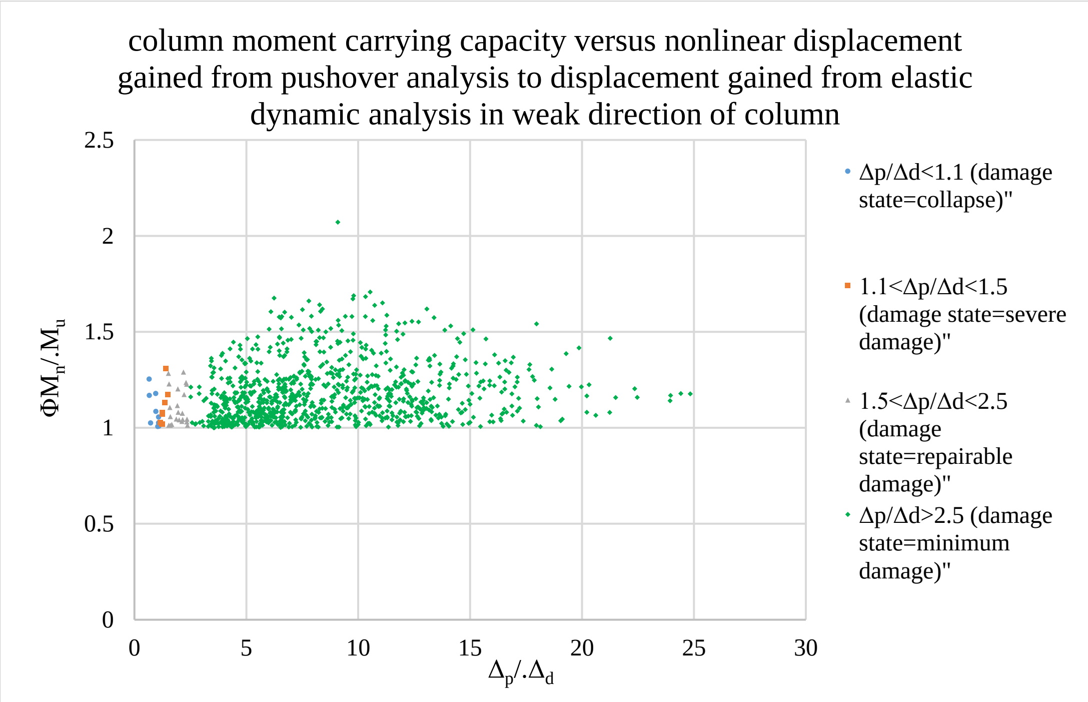


Figure 4.27. Column Moment Carrying Capacity versus Nonlinear Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Weak Direction of Column

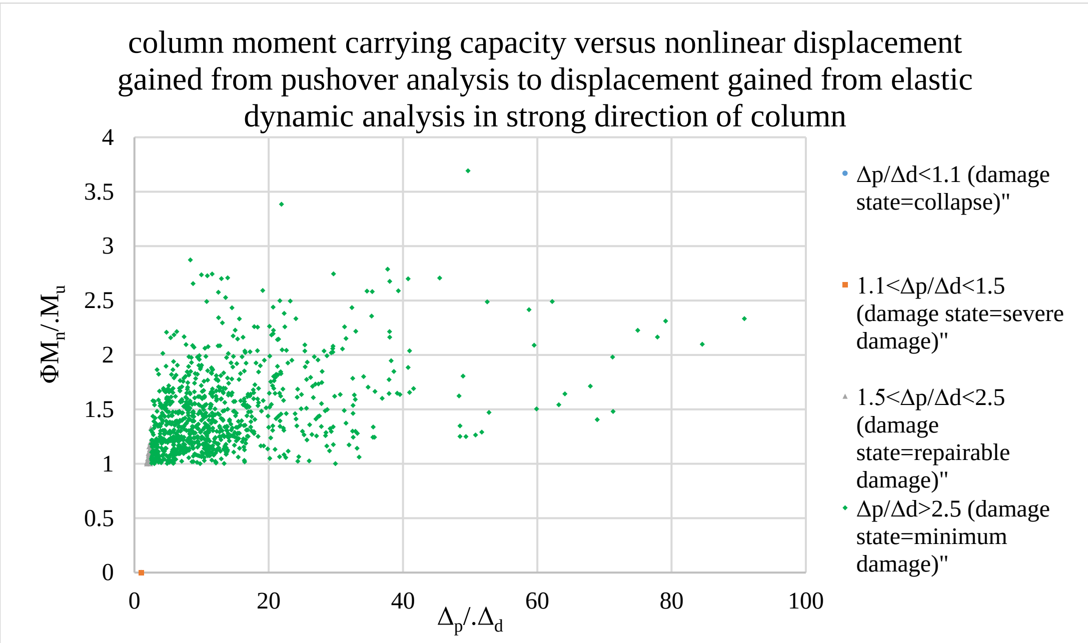


Figure 4.28. Column Moment Carrying Capacity versus Nonlinear Displacement Gained from Pushover Analysis to Displacement Gained from Elastic Dynamic Analysis in Strong Direction of Column

At the end of the design, it is observed that moment reliabilities of columns are in between 0.58 and 2.13 (probability of failure is approximately between 0.2810 and 0.0166) in weak direction and they are in between 0.58 and 4.90 (probability of failure is approximately between 0.2810 and 0.0000) in strong direction. This shows that columns are generally yielding in weak direction since reliabilities are generally lower in that direction. However, as it is stated and commented before, in pushover analysis, the structure has proven to have more displacement capacity to failure. Therefore, the collapse reliabilities shall be determined from pushover analysis and the other damage state probabilities shall be determined from moment reliabilities. Column displacement reliabilities are in between 0.97 and 11.99 (probability of failure is approximately between 0.1660 and 0.0000) in weak direction and they are in between 4.83 and 12.24 (probability of failure ~ 0).

Pushover collapse displacement ratio to seismic demand displacement is generally larger than 2.5 which is representing minimum damage state for columns designed for nominal moment capacity. Therefore, nominal moment capacities represent minimum damage state. During design of earthquake, it has been proven that probability of having minimum damage is high since reliability for this limit state is low. For collapse limit state, the probability is low and reliability is high.

Based on the analysis results, additional comments are given below:

- Span number does not affect the results much, and it cannot be said that larger span number means more moments at columns or else. Because it changes for different bridges.
- Spectrum type 6 leads higher results compared to others for all analysis. After that, spectrum type 4 comes. This means that soil condition type ZD is the worst condition to locate a bridge when it is designed using specification "AASHTO LRFD". Spectrum type 2 may cause less or more moments in columns than the types 3 and 5. However, spectrum type 2 is always worse

condition than the type 1 and also the type 5 is worse than the type 3 and 1. In addition the type 3 is worse than 1 (larger moments acting on columns).

- Deck width span length and column height directly increase the moments acting on columns when they are increased. However, considering the case of increase amount is the same for deck width, span length and column height (for example, twice for all), most effective way to increase moments acting on columns is increasing deck width. After that increasing span length is the most effective way to increase the moments. Column height increase is not such an effective way when compared to the others to increase the moments.
- Different skewness condition is more complicated issue according to the other conditions mentioned above. The more skewness is used, the higher moments are gained. However, this is not directly because of skewness but the larger dimensions of columns. In other words, larger skewnesses means having longer cap beams and so larger column dimensions. This cause increase in moments. Yet, this increase may change for longitudinal direction and lateral direction of bridge. Because the skewness change affects the direction of columns placed in bridges.

CHAPTER 5

CONCLUSION

The reliability and the quantity of the columns placed in the bridges located in a seismically active region are identified. In the light of this research, it could be deducted that columns are generally designed to have high stiffness per Turkish engineering practices that does not allow much displacement compared to ductile columns. Meanly, columns are generally designed as elastic and brittle in Turkey. Therefore, the displacement limits are not exceeded due to high stiffness. Having high stiffness in design can attract large seismic forces that may not be resisted by the columns. In Turkish practice, usually large sections with 1% reinforcement ratio are preferred compared to small sections having high amount of reinforcement. Such an approach yields high stiffness to columns. Having small sections with less rigidity can trigger displacement based failures. Investigation of Turkish data yields to high uncertainty (high c.o.v) in assessment of seismic acceleration and dynamic modeling that decreases the reliability as expected. The same observation is true for many countries. Using AASHTO LFD or AASHTO LRFD does not much change the reliability results. In many cases, the same reliability can be achieved using smaller sections with high ratio of reinforcement compared to larger sections with 1% reinforcement ratios. It can be concluded that using less stiff columns will be beneficial in terms of cost of column and foundation.

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APPENDICES

Appendices are in the CD attached at the end.

A. TYPICAL CROSS-SECTIONS OF THE STRUCTURAL PARTS
B. COLUMN CROSS-SECTIONAL AREA AND REINFORCEMENT
C. CALCULATION DETAILS OF COLUMNS BASED ON RELIABILITY ANALYSIS
D. CALCULATION DETAILS OF COLUMNS BASED ON PUSHOVER ANALYSIS