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SEISMIC EVALUATION AND RETROFIT OF AN EXISTING BRIDGE BY USING CURRENT CODES OF PRACTICE

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ABSTRACT

Taking into account the environmental impacts and the improvement of the current codes of practice, the seismic evaluation and if so necessary the retrofit of existing bridges is of paramount importance. In this context, this paper is concerned with İstanbul-Yeşilköy Demiryolu Caddesi Overpass Bridge. The study started by performing detailed material tests, in situ observations and measurements of the bridge superstructure and the foundation system. Following the completion of the inspection and data collection stage, a 3-dimensional structural model has been established and seismic performance of the structure has been determined by making use of the current DLH Code of Practice. The results obtained have been evaluated and alternative technical solutions were compared with respective costs. Finally, the required structural repair and seismic retrofit measures have been taken.

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Taking into account the environmental impacts and the improvement of the current codes of practice, the seismic evaluation and if so necessary the retrofit of existing bridges is of paramount importance. In this context, this paper is concerned with İstanbul-Yeşilköy Demiryolu Caddesi Overpass Bridge. The study started by performing detailed material tests, in situ observations and measurements of the bridge superstructure and the foundation system. Following the completion of the inspection and data collection stage, a 3-dimensional structural model has been established and seismic performance of the structure has been determined by making use of the current DLH Code of Practice. The results obtained have been evaluated and alternative technical solutions were compared with respective costs. Finally, the required structural repair and seismic retrofit measures have been taken.

1. Introduction

The province of Istanbul possesses a rapidly improving metropolis due to its population in excess of 14 million and to its unique intercontinental position. As the city gets more and more crowded, apart from the fact that temporary and permanent remedial solutions should be looked for in order to enhance the capacity of highway, railway, maritime and air transportation, the existing systems should also be regularly inspected, repaired and maintained and so required be strengthened and retrofitted so as to ensure a good quality service free of major problems throughout their service life.

Within the scope of this study it has been aimed at giving information concerning the methods of evaluating of bridges under seismic effects and relevant calculation methods and the application of such studies on Yeşilköy Demiryolu Caddesi Overpass Bridge which is currently being prepared and retrofitted.

The Yeşilköy Demiryolu Caddesi Overpass Bridge which has been studied is a 3 span continuous orthotropic deck steel box bridge resting on circular pier columns. The bridge with a total length of 71.5 m is depicted in Figure 1.1.

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Figure 1.1. General view of the bridge.

2. In Situ Observations and Tests

As the original bridge drawing were not available, in situ dimensional measurements had to be taken; in addition, detailed bridge location plan map was prepared and the locations of planned bridge soil boring tests were marked on it and finally soil boring and excavation license was issued from the appropriate Municipality departments and soil investigation work was thus completed by also making use of geophysical methods.

Concrete core specimens and steel member samples were extracted from the structure, thereby enabling the determination of material strength as a result of tests performed at ITU Material Laboratory. As a result of such tests it was found that concrete compressive strength and structural steel tensile strength values were 22.2 MPa and 425.5 MPa respectively.

3. General Principles of Seismic Evaluation

In this study the calculations and evaluation has been performed in accordance with the clauses of "DLH, General Directorate for Construction for Railways, Harbour and Airports (Ministry of Transportation) which is accepted by the Client; where required reference was also made to FHWA Seismic Retrofit Manual for Highway Structures: Part1-Bridges, FHWA-HRT-06-032, 2006 Code of Practice.

The bridge class has to be determined initially which would enable to decide the bridge seismic level and hence the corresponding evaluation method during the calculation. The DLH Code considers 3 separate classes for bridges, namely "special" bridges, "ordinary" bridges and "simple" bridges. According to the code, "special" bridges are treated as bridges located on strategic highway sections and critical bridges expected to be used immediately after an earthquake. Yeşilköy Demiryolu Caddesi Overpass Bridge has been declared by the Client as a "special" bridge due to the presence of an important road under it which should be kept open to traffic after an earthquake.

According to the Code, the special bridges have to evaluated for different performance behavior at 2 different seismic levels. One level is such that the exceedence probability is 10 percent with a return period of 475 years, as namely seismic hazard level D2. At this level Strength Based Evaluation (SBE) method is used, and the seismic behavior of structural members is determined by comparing Minimum Damage (MD) performance limits.

Multimode spectral analysis method was used within the scope of strength based evaluation. The response spectra derived for 3 separate seismic levels depending on bridge longitude and latitude values is shown in Figure 3.1

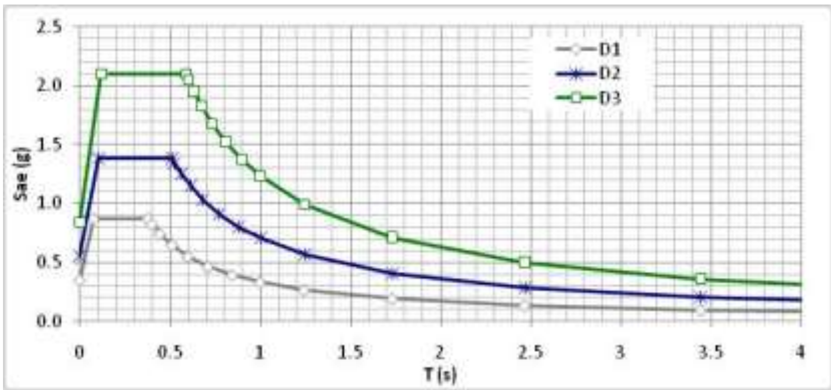

Figure 3.1. Seismic Response Spectrum [DLH 1.2.2.1 & 1.2.2.2]

The other seismic level considered in the calculations is the D3 seismic hazard level earthquake with an exceedence probability of 2 percent corresponding to a return period of 2475 years. Deformation based evaluation (DBE) is being used at this level and the seismic behavior of structural members is determined by comparing Limited Damage (LD) performance limits.

Within the scope of deformation based evaluation approach, nonlinear time history calculation method has been used. Table 3.1 shows the 7 different seismic record data and corresponding parameters. The records were deduced from PEER data base.

Table 3.1. Seismic records used in NTH analysis.

Earthquake	Date	M	Record/Component	HP (Hz)	LP (Hz)	PGA (g)	PGV (cm/s)	PGD (cm)
KOCAELI	17.08.1999	7.4	KOCAELI/IZT090	0.1	30	0.22	29.8	17.12
DUZCE	12.11.1999	7.1	DUZCE/BOL090	0.05	null	0.822	62.1	13.55
ERZINCAN	13.03.1992	6.9	ERZINCAN/ERZ-EW	0.1	null	0.496	64.3	22.78
NORTHRIDGE	17.01.1994	6.7	NORTHRIDGE/SYL090	0.12	23	0.604	78.2	16.05
IMPERIAL VALLEY	15.10.1979	6.5	IMPVALL/H-BRA315	0.1	40	0.22	38.9	13.46
KOBE	16.01.1995	6.9	KOBE/TAK090	null	null	0.616	120.7	32.72
EL CENTRO	19.05.1940	7	IMPVALL/I-ELC180	0.2	15	0.313	29.8	13.32

4. Strength and Deformation Based Seismic Evaluation of the Bridge Structure

4.1. Structural Model

SAP2000 software was used in calculations. As illustrated in Figure 4.1, the bridge superstructure, columns and piles were modeled by frame members. For abutments however, a separate model was prepared consisting of shell members.

The path traced in the preparation of the structural model is illustrated in the flowchart, given in Figure 4.2.

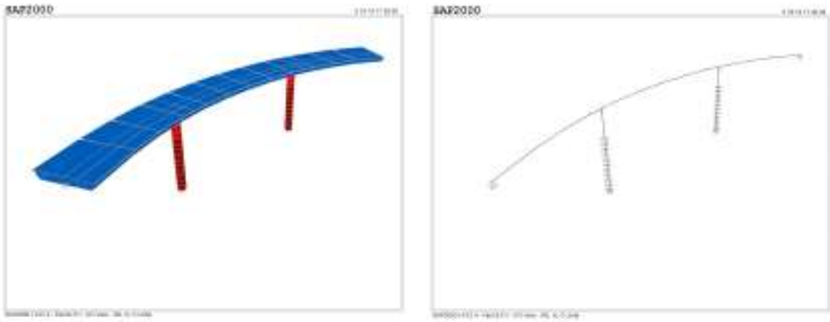

Figure 4.1. General view of Bridge Structural Model

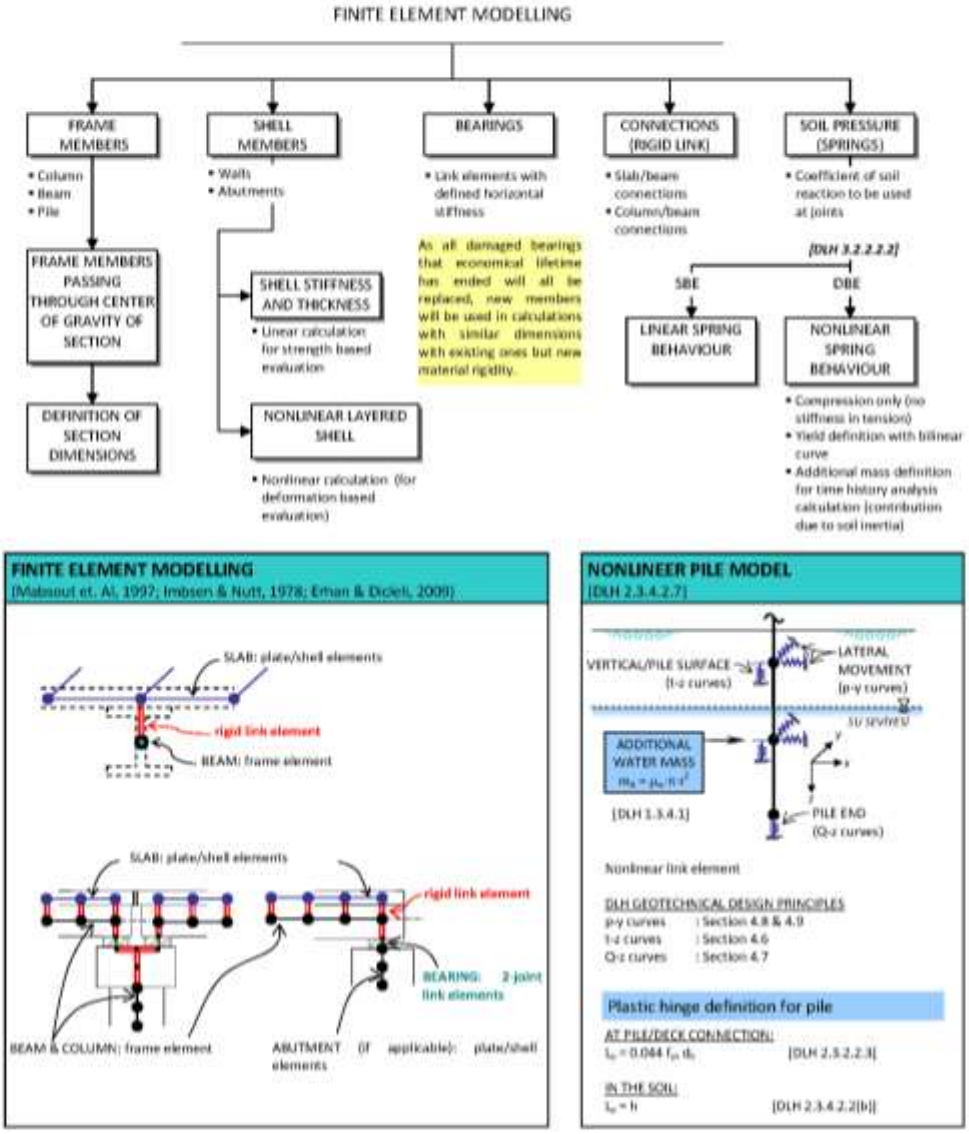

Figure 4.2. Flowchart relating to finite element modeling

4.2. Strength Based Evaluations

In the strength based evaluation method (SBE), starting with the linear elastic behavior of the structure, seismic effects are determined and these effects are evaluated by demand/capacity ratio (D/C). The capacity/effect ratio method is used in accordance with the definitions made in FHWA Seismic Retrofit Manual 2006 section 5.4 –method C.

The surplus capacity is to be taken into account as follows:

$$r = \frac{C - D_g}{D_{EQ}} \tag{4.1}$$

where, r is the demand/capacity ratio, C is the section capacity, D_g is the effect of vertical loading (except that due to seismic loading), D_{EQ} is the effect due to seismic loading. For all bridge members, the capacity is considered adequate where the demand/capacity ratio(r) is greater than 1, is considered inadequate where this ratio is less than 1.

The flowchart pertaining to calculations performed in accordance with the strength based evaluation method is illustrated in Figure 4.3.

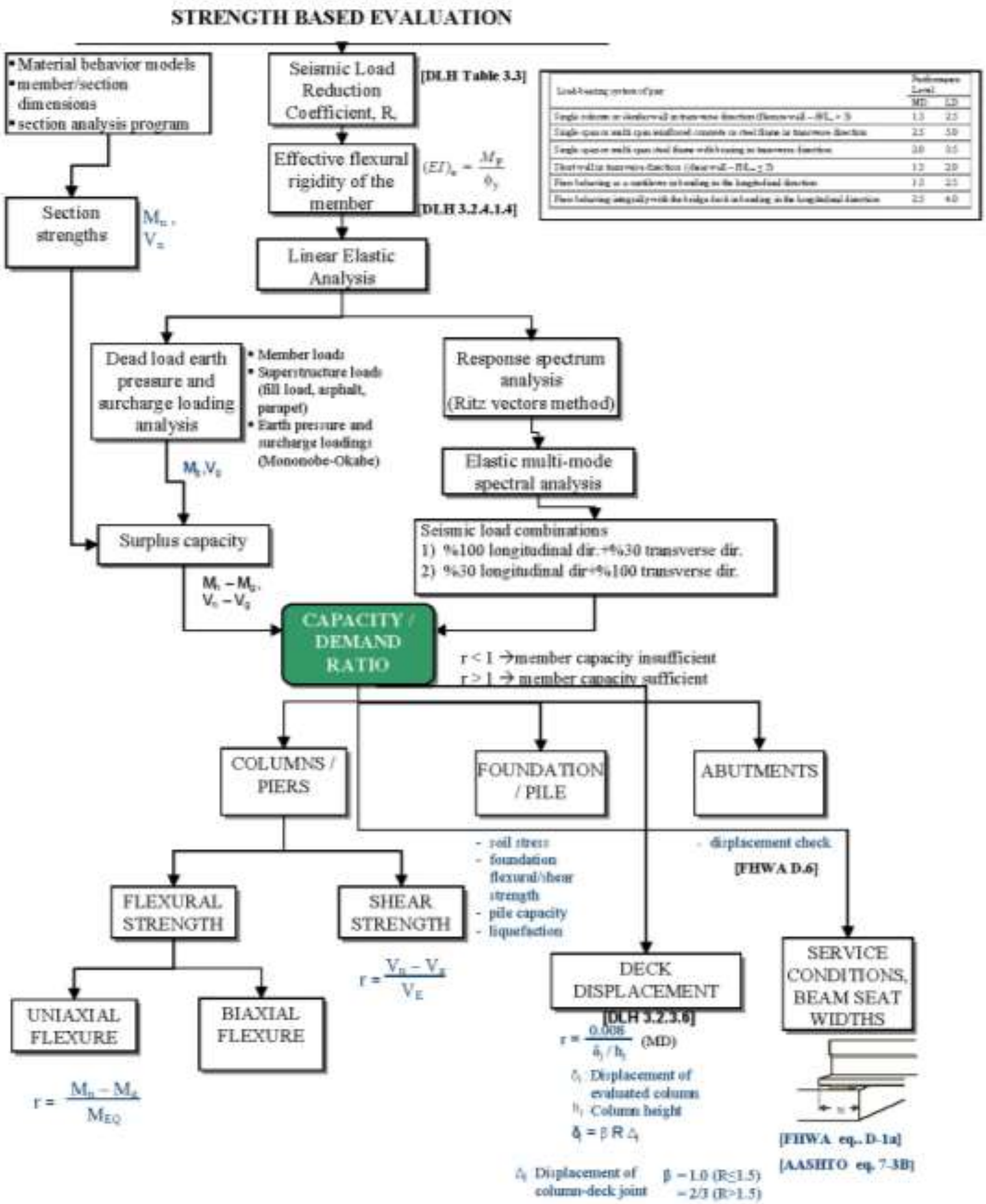

Figure 4.3. Flow chart of Strength Based Evaluation

Column/Wall Flexural and Shear Strength

In columns and walls, demand/capacity ratio in two dimensional flexure is determined from a two dimensional bending moment interaction diagram accompanied by a vertical load. The bending moment effects in the diagram in both directions due to vertical loads are reduced in order to deduce the required reduced capacity. The demand/capacity ratio can be found by dividing the reduced flexural capacity by the resultant of seismic moments. This procedure is explained in Figure 4.4.

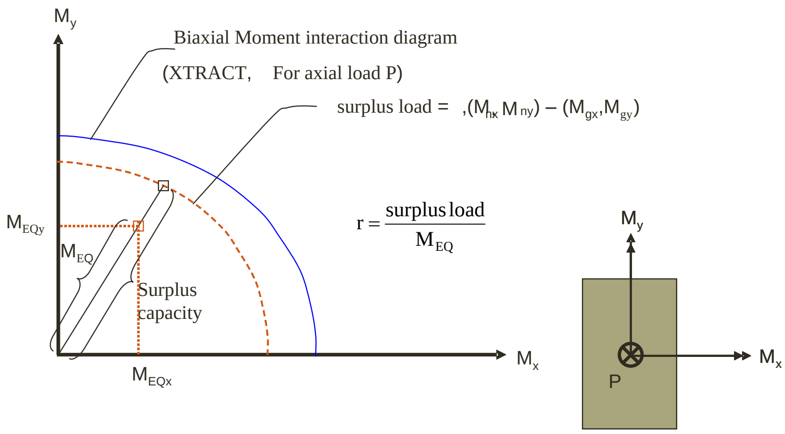

Figure 4.4. Calculation of column capacity/demand ratio

The demand/capacity ratio of bridge columns in shear is determined from the column surplus shear capacity of shear forces derived from the analysis.

Column/Wall Relative Displacement Limit

For columns, relative displacement ratio is evaluated, in addition. The displacement limits at the column deck joint zone is given in the DLH 2008 Code (DLH Code 2008,3.2.3.6).

$$\delta_j = \beta R \Delta_j \qquad (4.2)$$

where, δ_j is the displacement which the evaluation be based upon, Δ_j is the pier-deck joint displacement, R is the behavior performance coefficient (R will be taken as equal to 1 provided that the displacements calculated from the analysis model is not reduced, and coefficient β=1 for R=1.5, otherwise β=2/3).

The displacement subject to evaluation so calculated were divided by column heights in order to obtain relative displacements (δ_j / h_j). The relative displacement limits are given as 0.008 for minimal damage and 0.015 for limited (controlled) damage situation (DLH 2008, 3.2.3.6).

Seismic Load Reduction Coefficient

In the course of the evaluation of bridge piers and abutments by the strength based evaluation method (SBE) the influence of a possible nonlinear behavior which may be observed at minimum damage level (MD) upon the energy damping is taken into account by reducing seismic forces by certain amounts depending on the type and ductility of the structural member.

For bridges with different types of piers, the bridge load bearing system performance coefficient is calculated from the weighted average of the piers concerned.

Where R ≤ 1.5, seismic load reduction factor is taken as Ra(T) = R. For cases where R > 1.5 however, Ra(T) is determined based on the natural vibration period T as 1.5 + (R – 1.5)×(T/TS) [DLH 3.2.3.2.2], where T is the first natural vibration period of the bridge load bearing system and T_s is the spectrum corner period.

4.3. Deformation Based Evaluation

The nonlinear time history analysis method of calculation with respect to deformation based evaluation, as the bridge is on a horizontal curve. For the time history analysis, 7 separate seismic records given in Table 3.1 were used which were scaled by the main adopted seismic spectrum. The response spectra pertaining to acceleration –time records which match the D3 seismic level target spectrum due to Seismomatch software is depicted in Figure 4.5. The mean internal section force, displacement and deformation effects derived from the time history analysis were used in the evaluation. Figure 4.6 depicts the flowchart due to deformation based evaluation.

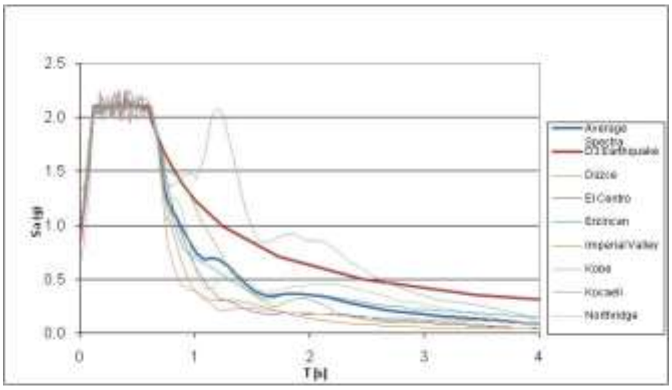

Figure 4.5. Response spectrum graphic of matched acceleration-time records

The Evaluation of Member Deformations due to Seismic Load

The unit deformation limits in accordance with the required performance level has been taken as equal to the values given in DLH.

The unit deformation limits given in Table 4.1 have been transformed into the equivalent curvature and/or rotation values by using the section moment-curvature (M-K) analysis.

Table 4.1. Unit Deformation Limits Defined for Pier Plastic Sections [DLH 2008 Table 3.4]

Unit deformation	Performance level	
	MD	LD
Unit deformation of concrete in compression, $\boldsymbol{\varepsilon_c}$	0.004	0.020
Unit deformation of reinforcing steel, $\boldsymbol{\varepsilon_s}$	0.010	0.040

In accordance with Equation 4.3, the concrete unit deformation for limited damage

(LD) limit in compression has been taken as variable between 0.004 and 0.020.

$$KH = 0.004 + 0.016 \cdot (\rho_s/\rho_{sm}) \leq 0.020 \qquad (4.3)$$

where; ρ_s : volumetric stirrup ratio used in column
ρ_{sm}: minimum stirrup ratio as required in the current code of practice

SBE used in the shear strength evaluation corresponding to brittle collapse mode, during the deformation based evaluation as well.

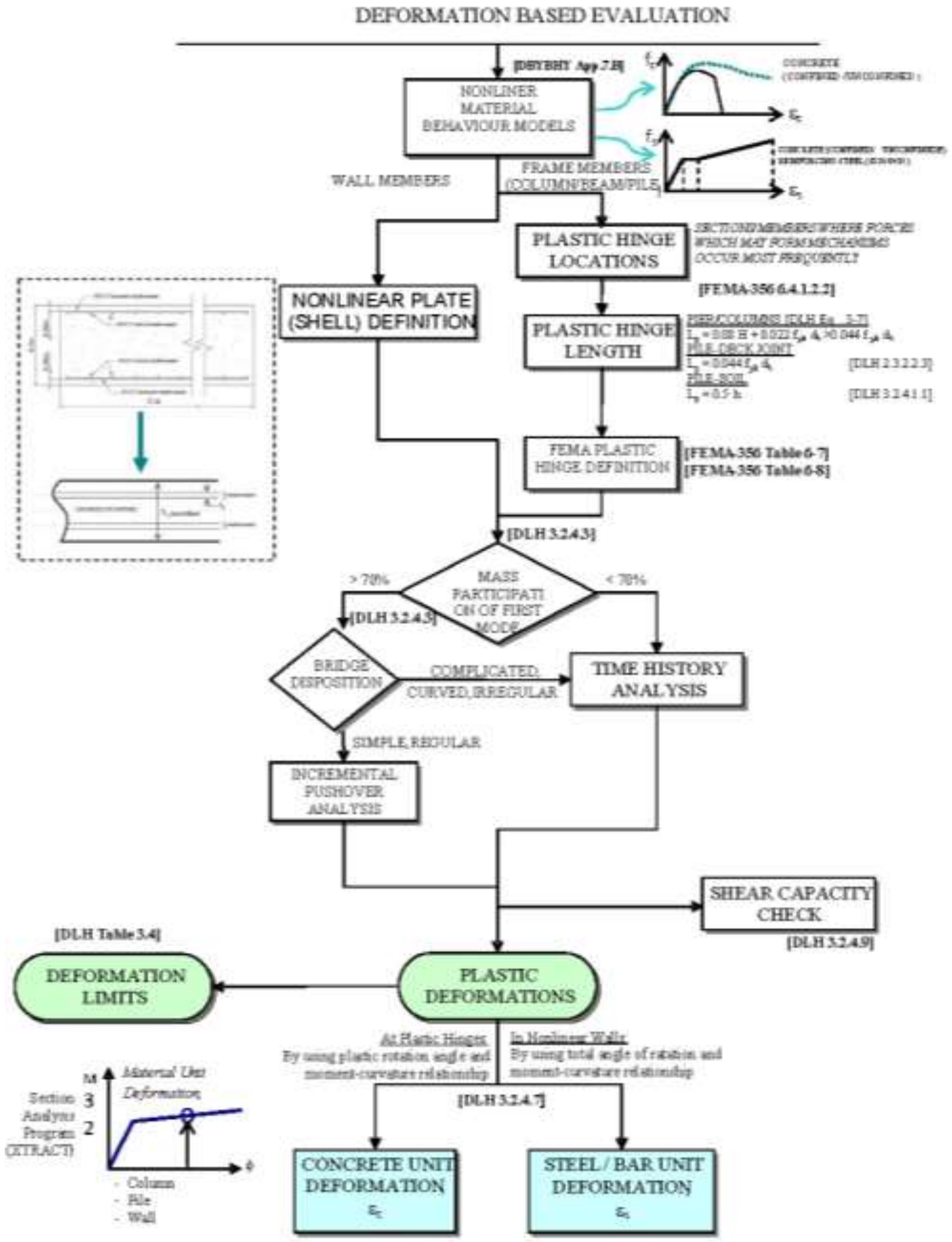

Figure 4.6. Flow chart of Displacement Based Evaluation

4.4. Evaluation of Results

During the calculations it has been observed that the member capacities other than those of bearings were rather high. The results of the calculation are depicted in Table 4.2 and in Table 4.3 for SBE and DBE respectively.

Table 4.2 Summary of results due to SBE

MEMBER EVALUATED		r (Demand/Capacity)	RESULT
FLEXURAL CHECK	Pier	5	≥ 1.00 ADEQUATE
	Abutment	11.82	≥ 1.00 ADEQUATE
SHEAR CHECK	Pier	3.80	≥ 1.00 ADEQUATE
	Abutment	32.00	≥ 1.00 ADEQUATE
ISOLATED FOOTING CHECK	Abutment	4.00	≥ 1.00 ADEQUATE
DECK DISPLACEMENT CHECK		6.97	≥ 1.00 ADEQUATE
BEAM SEAT WITH CHECK		2.29	≥ 1.00 ADEQUATE
SEISMIC BUFFER CHECK		0	< 1.00 INADEQUATE

Table 4.3 Summary of results due to DBE

DEFORMATION EVALUATION	CALCULATION	LD LIMIT	RESULT
CONCRETE	-	0.020	PLASTIC HINGE DID NOT OCCUR. ADEQUATE
REINFORCEMENT	-	0.040	PLASTIC HINGE DID NOT OCCUR. ADEQUATE

It has been observed that the elastomeric bearings used at pier have never been changed since their original installation. As results of calculations, the fixed bearings at abutments are found to be inadequate hence it became clear that solutions such as changing the abutment bearings and revising the bearing conditions of bridge deck should be considered.

5. General Principles of Seismic Retrofit

In order to be able to replace elastomeric bearings, temporary steel gussets have been foreseen in the upper part of columns. These elements are designed taking into account the capacity of jacks which are required to lift the superstructure. Temporary steel gusset is depicted in Figure 5.1.

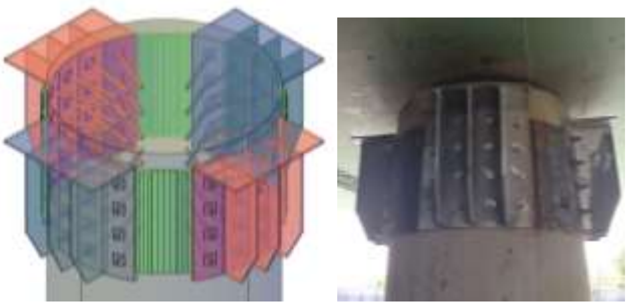

Figure 5.1. Temporary steel gussets

Even alternatives generated, it is decided to design additional seismic buffers to avoid interrupting the flow of traffic. Seismic buffers designed to resist whole seismic forces coming from superstructure. Therefore, prevention against to a potential failure at bearings under seismic effects is provided. Related detail depicted in Fig.5.2.

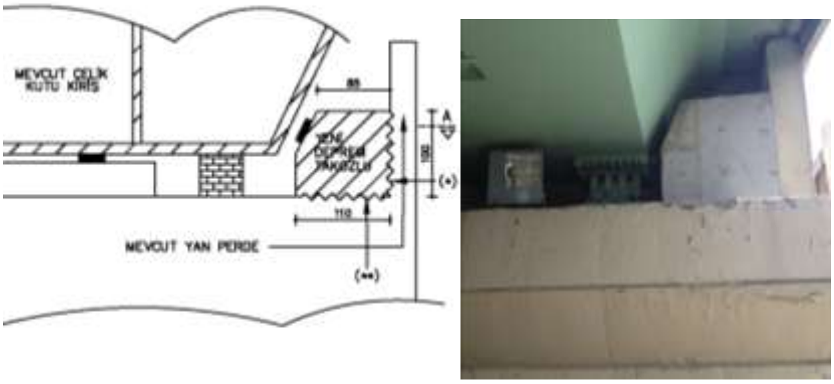

Figure 5.2.   Abutment seismic buffers

It is proposed to apply conventional retrofitting methods for nonstructural elements of the bridge.

6. Conclusion

In this study, the behavior of an existing bridge structure is evaluated under seismic effects, by using the principles given in DLH Code of Practice. In this context, the flow charts including approaches and methods of analysis are given with summary information about related specifications. According to the analysis results, insufficient elements of bridge are identified and the necessary measures for seismic retrofit are explained.

Considering seismic conditions of our country, necessity of seismic evaluation and if necessary retrofit measures to be taken of existing bridge structures according to the current seismic codes is obvious. Hence periodic evaluation and periodic maintenance should be done without hindering and risk assessments should be identified correctly.

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