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DETERMINING A METHOD OF DYNAMIC ANALYSIS FOR THE VIADUCTS WITH GEOMETRIC IRREGULARITY AND INVESTIGATION OF THE SEISMIC PERFORMANCE OF NURTEPE VIADUCT

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ABSTRACT

In this paper, we carried out calculations by the use of different methodologies in order to determine earthquake performances of geometrically irregular viaducts. The results of this analysis have been evaluated along with the carrying elements of the structure. Throughout the study, different Dynamic Analysis methods for bridges and viaducts, [Pushover (single-mode, multi-mode), Time History] have been tried, and the question of which methodologies could be employed depending on the state of the structure has been investigated.

We prepared an earthquake data and established a system model, both of which were reproduced for the Time-History method that was defined as a result of the analysis at the Nurtepe viaduct. Subsequently the elements of the structure have been checked; at the foundation solutions, the loads coming to the foundations have been determined as phases; and foundation solutions have been obtained considering which kind of loads was carried by which part of the retrofitted foundations. At the end of all these works, designation of the analysis method for this kinds of viaducts, preparation of analysis models, interpretation of their results, and the evaluation of the entire system have been carried out.

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We prepared an earthquake data and established a system model, both of which were reproduced for the Time-History method that was defined as a result of the analysis at the Nurtepe viaduct. Subsequently the elements of the structure have been checked; at the foundation solutions, the loads coming to the foundations have been determined as phases; and foundation solutions have been obtained considering which kind of loads was carried by which part of the retrofitted foundations. At the end of all these works, designation of the analysis method for this kinds of viaducts, preparation of analysis models, interpretation of their results, and the evaluation of the entire system have been carried out.

Introduction

New techniques have been recently developed to investigate the performances of bridges and viaducts. Some of these techniques are complicated while the others are simplified. How complicated a structure is (variability in height of the piers, kurb etc.) pivotal in the determination of the method. In this respect, Nurtepe Viaduct is a good example in terms both its being kurb, and the variability in the height of its legs. One-mode pushover and Time History Analysis methods have been used in the calculations. Analysis has been done by comparing the results of these calculations in order to reach the most applicable calculation method.

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Information about the Viaduct

Nurtepe Viaduct is on the connection road between the TEM – Okmeydani interchange. It is 400m in length and with a total of 10 spans. The width of the superstructure is 13m; and the width of the highway is 11m. The Piers are composed of the columns with H-cross-section. The Beams sits on elastomeric bearings in different thicknesses. The distances between the axles of the bridge are 40m each, and Superstructure is Prestresed precast omega beam and cast in place slab (thickness: 25cm)

Figure 1: View of Nurtepe Viaduct

Explanations about the calculations

Mathematical model details

The analysis of the Nurtepe Viaduct has been carried out firstly with the use of one-mode pushover analysis, and all of the results (mass participation, displacements and internal forces) have been checked. In the second phase, Time History method was used because the mass participation in the direction of the width remained around 60%. For this purpose, 7 earthquake data have been derived, which are compatible with the spectrum given in the following parts. The data that was derived in two main directions and for each earthquake was transmitted to the structure at the same time, and calculations were done accordingly.

Throughout the modeling work, foundations of the bridge were also taken into consideration, and in the dynamic analysis the effects that were formed because of the rotations in the foundations were included in the model. Especially the high-level rotations that take place in the foundations while they are in their existing dimensions reduced the inner forces influencing the structure. However, relatively large stress and pulling parts have been detected. In the Pushover analysis that was carried out after the enlargement of the foundations, no significant difference have been detected between the acceptance of fix-end column bases and identification of the retrofitted foundations. Therefore, the time-history analysis, which takes long time, was carried out for the ankastre cloumn base condition.

Crack section stiffness was used in piers. One plastic hinge was identified for each column.

Bridge superstructure was modeled as a frame member. All cross-section characteristics of the superstructure were calculated, and assigned to the frame defined in the center of gravity point of the superstructure. The continuity of the superstructure was cut at the cross-sections where the expansion joints are.

The superstructure was accepted as fixed in the transverse direction. In longitudinal direction; for compression, gap elements were used to define seismic buffers and for tension, hook elements were used to define tension bars. Because the question of which elastomeric bearing thickness was used in which axle was not clarified in the original as-built drawings of the viaduct, it was defined according to the system in the viaducts that were similarly built (Levent, Sadabad, Karasu, Ispartakule viaducts).

Seismic Datas

Time History analysis was carried out for the D-2 seismic level given in the DLH instructions. The D-2 seismic level refers to the earthquake movement, which has a probability of 10% for being exceeded in 50 years, and a recurrence period of 475 years. The spectrum that belongs to this earthquake movement is given below. 7 earthquake datas were produced, which are compatible with the spectrum chosen with the Time History analysis. The data that was produced in both vertical directions was channeled to the structure, and the analysis was carried out.

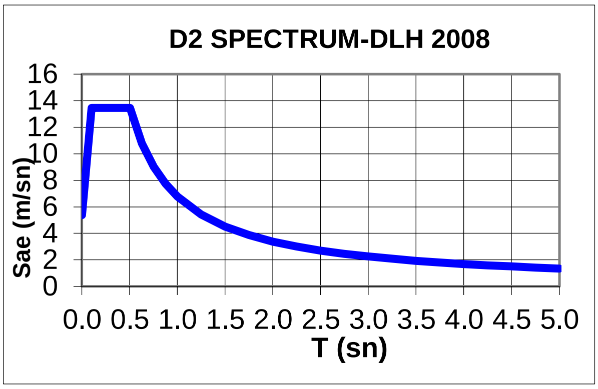


Figure 2: D2 Spectrum

The details related to the spectrum and the compatible earthquake data are given in the following sections.

Table 1. Tables of Performance Level [1]

Seismic Level	Normal Bridge		Special Bridge	
D2	Limited	Important	Continious	Repairable

The limits of the strain values, which are to provide the desired performance at the D2 seismic levels, and so, which will be used in the reinforced concrete sections are given in the following.

Table 2. Tables of strain limits [1]

Seismic Level	Deformation limits for Unconfined Concrete		Deformation limits for Confined Concrete	
	Concrete	Steel	Concrete	Steel
S2	0.0027 (Pressure)	0.04 (Çekme)	0.012 (Pressure)	0.04 (Tension)

Material specifications

Table 3. Tables of Concrete specifications[7]

Class	Cylindrical Strength (MPa)	Elasticity Modulus (MPa)	Members
C25	25	23650	All substructure and slab
C20	20	21153	Piles
C40	18	29915	Prestressed Precast Beams

These values are reduced at a 1.5% rate, compatible with the spectrum that was used according to the limits given for the S2 seismic level (2% probability of being exceeded in 50 years).

Table 4. Tables of Steel specifications[7]

Type	Yield Strength	Ultimate Strength	Usage
IIIa	500 Mpa	420 Mpa	**All members (except pile stirrups)**
I	275 Mpa	220 Mpa	**Pile stirrups**

Mathematical model shapes

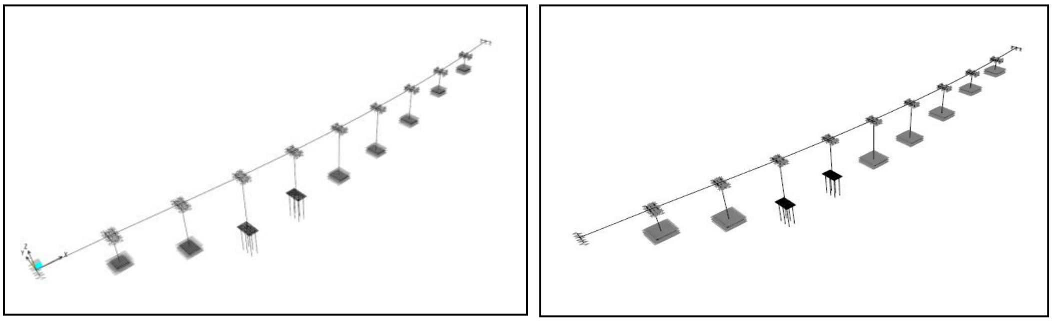


Figure 3. Seismic Model of Nurtepe Viaduct Existing and retrofitted situation[6]

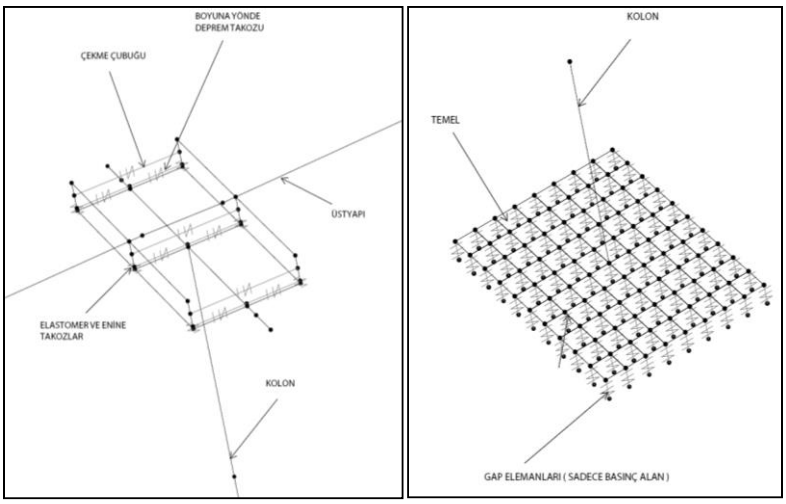


Figure 4. Seismic Model of Nurtepe Viaduct Pier Cap and Foundation Details[6]

Results of Pushover Analysis

The Pushover analysis of Nurtepe Viaduct were carried out with three different modeling approaches. First of all, on the existing foundation of the system model with the actual size of the model system is solved by the addition of. Secondly, the system was analyzed with the use of the retrofitted foundation dimensions at the spread foundations. The third and final analysis consists of the condition where the column bases are ankastre.

Foundation dimensions were defined in the Pushover analysis model, so that the rotations that were to happen in the foundations were going to increase the modal periods of the system. In this way, the smallest forces that are to come onto the existing foundations have been investigated, and the amount of stress and tension under these powers has been calculated. Finally it has been decided if the foundations are enough or not.

- In the static analysis, the prevailing modes mass participations in each main direction are at the levels of 70% and 65% as shown in table 3,4,5 according to the viaduct longitudinal direction. It has been observed that especially the short piers do not join the movement during the prevailing modes, so that mass participations remained low.

Table 3. Pushover Anaysis Modal Participating Mass Ratios (With Dimensions of existing Foundation, X : Longitudinal Direction ,Y : Transverse Direction)

OutputCase	StepType	StepNum	Period	UX	UY	SumUX	SumUY
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless	Unitless
MODAL-PUSH-X	Mode	1	2.839835	**0.720**	0.000	0.720	0.000
MODAL-PUSH-Y	Mode	1	2.569701	0.000	**0.670**	0.000	0.670

Table 4. Pushover Anaysis Modal Participating Mass Ratios (With Dimensions of Retrofitted Foundation)

OutputCase	StepType	StepNum	Period	UX	UY	SumUX	SumUY
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless	Unitless
MODAL-PUSH-X	Mode	1	2.69877	**0.700**	0.000	0.700	0.000
MODAL-PUSH-Y	Mode	1	2.433972	0.000	**0.640**	0.000	0.640

Table 5. Pushover Anaysis Modal Participating Mass Ratios (Fix Column connection)

OutputCase	StepType	StepNum	Period	UX	UY	SumUX	SumUY
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless	Unitless
MODAL-PUSH-X	Mode	1	2.645517	**0.712**	0.000	0.712	0.000
MODAL-PUSH-Y	Mode	1	2.377464	0.000	**0.649**	0.000	0.649

-According to Pushover analysis is made using the existing dimensions of foundation occurring tension range area, and percent tensile stresses generated are shown in Table 6 below.

Table 6. Table of Existing Spread Footing results of Nurtepe Viaduct,

Axes	Type of Foundation	Dimensions	Existing Situation(Longitudinal Direction)		Existing Situation (Transverse Direction)		Allowable soil stress (F.S.: 1.5)
			Ratio of Tension Area	Stress	Ratio of Tension Area	Stress	
		m		kN/m2		kN/m2	kN/m2
P1	Spread	8.5x7.5m2m	80%	3067	56%	1413	1013,8
P2	Spread	11x7.5x2m	60%	1465	56%	1257	980,7
P5	Spread	11x8.5x2m	30%	825	45%	1027	824,45
P6	Spread	11x7.5x2m	60%	1465	56%	1257	989,3
P7	Spread	11x7.5x2m	60%	1465	56%	1257	980,7
P8	Spread	8.5x7.5m2m	80%	3067	56%	1413	1013,8
P9	Spread	8.5x7.5m2m	80%	3067	56%	1413	1013,8

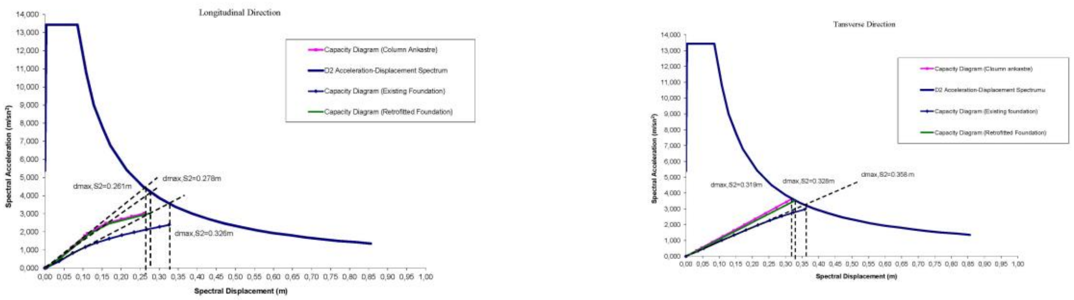


Figure 5. Pushover Analysis in Longitudinal and Transverse Direction D2 Seismic level Acceleration-Displacement Spectrum and Capacity Diagram

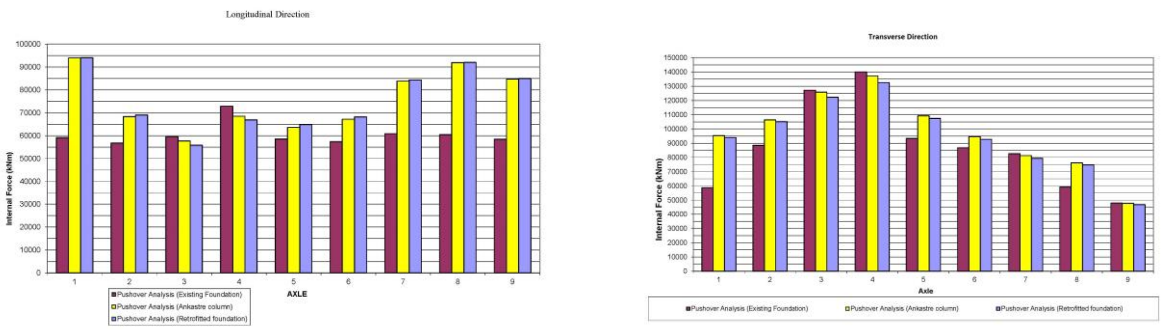


Figure 6. Comparison of İnternal force of Nurtepe Viaduct (Longitudinal and Transverse Direction)

- According to these results, the tension area percentage exceeded the limits in all spread foundations with the exception of P-5 axle in the transverse and longitudinal directions. Additionally, the tensions that take place are above the limits. According to the analyses carried out in this study, there is a need for retrofitting in all spread foundations.- The dimensions of the spread footings will be revised according to time history analysis because their modal participation mass ratio does not satisfy the requirements. After investigating the pushover curves in both directions, it can be seen that the capacity curve of the model, drawn after retrofitting the footings is so close to the capacity curve of the model which columns have fixed end assignments. So time history analysis of the model with fixed end columns will be run because of the reduction of time of analysis and convenience of evaluation of the results. By this method the reaction forces of columns and plastic rotation values will be on the safe side for decided earthquake performance level. The analyses for each spread footing will be done by these reaction forces. The main purpose of retrofitting the footings is to reduce the soil stress. The stress value under the footing should be smaller than the allowable stress value and the tension zone should be smaller than %50.

Steps of Time History Analysis

Preparation of Seismic Data

7 seismic data, which are consistent with D-2 seismic performance level spectrum (See figure 1) of DHL Specification, were prepared to be used at time history analysis of Nurtepe Viaduct. “Peer Ground Motion Database” software, which was submitted to internet by Berkeley University, was used to determine those data. For this purpose, first, the characteristics of expected earthquake for Istanbul Region was determined. And 7 equivalent earthquake data were chosen from this program. These were acceleration-time data. It was noted that the geometric mean of the spectrums of chosen data with 5% damping ratio was stayed in the interval of 90 and 110% of the D-2 Spectrum specified at DLH Specification. After these stages, 7 acceleration-time seismic records, which are consistent with the D-2 seismic performance level of DLH specification, were obtained for our analysis.

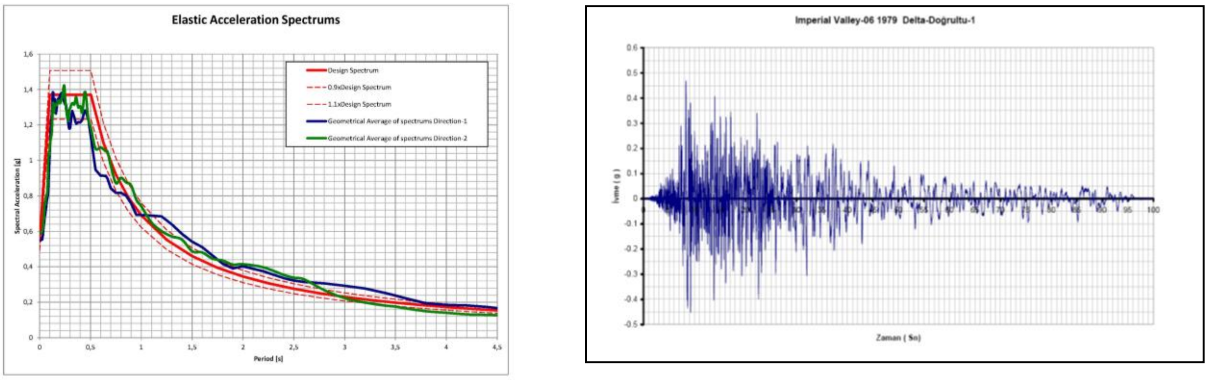


Figure 7. Design Spectrum Range and Geometrical Average of Selected Earthquake Spectrums and One of used seismic records

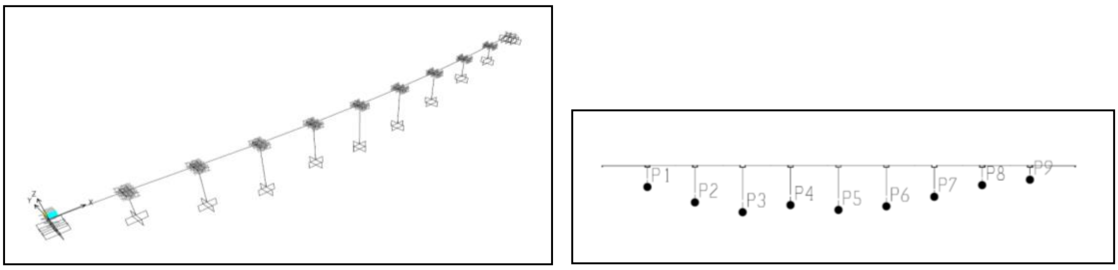
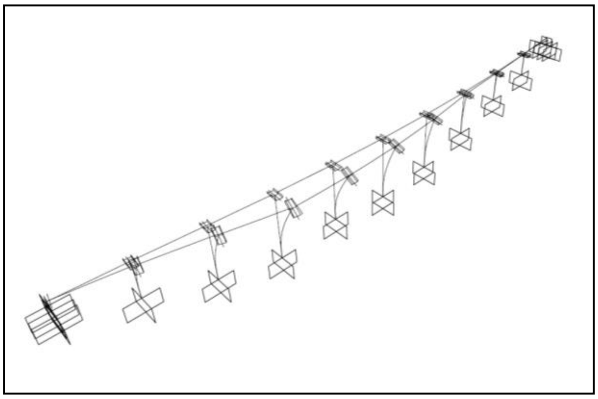


Figure 8. Time-History Model (Fix Column connection) and Plastic Hinges



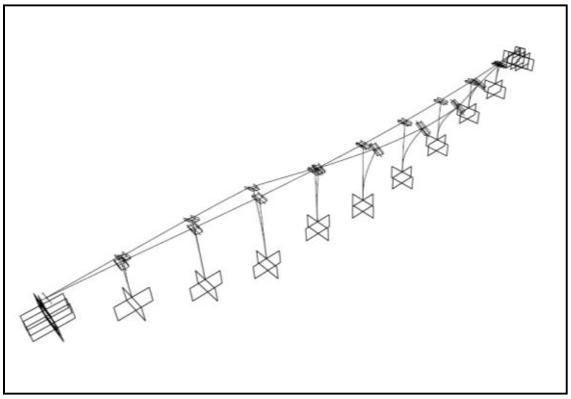


Figure 9. Mode shape-1 (T=2.459 s.) and Mode shape-2 (T=1.724 s.)

Table 7. Strain values in Longitudinal direction

Axles	Plastic Hinge Length	Plastic rotation	Plastic Curvature	Elastic Curvature	Total Curvature	Strain (Concrete)	Strain (Steel)
	m				(E-3)	(E-3)	(E-3)
P1	1,785	0,011	0,006	0,001	7,728	2,167	16,260
P2	2,86	0,001	0,000	0,001	1,676	0,973	3,562
P3	3,591	0,000	0,000	0,001	1,310	-	-
P4	3,049	0,001	0,000	0,001	1,644	0,983	3,565
P5	3,403	0,000	0,000	0,001	1,305	-	-
P6	3,143	0,000	0,000	0,001	1,309	-	-
P7	2,45	0,000	0,000	0,001	1,464	0,949	3,555
P8	1,643	0,006	0,003	0,001	4,812	1,646	10,390
P9	1,243	0,013	0,011	0,001	11,907	3,034	24,865

Table 8. Strain values in Transverse direction

Axles	Plastic Hinge Length	Plastic rotation	Plastic Curvature	Elastic Curvature	Total Curvature	Strain (Concrete)	Strain (Steel)
	m				(E-3)	(E-3)	(E-3)
P1	1,785	0,004	0,002	0,001	3,085	2,603	7,859
P2	2,86	0,003	0,001	0,001	1,853	3,465	10,830
P3	3,591	0,004	0,001	0,001	2,018	3,502	10,690
P4	3,049	0,005	0,002	0,001	2,638	3,481	10,780
P5	3,403	0,002	0,000	0,001	1,361	2,712	7,753
P6	3,143	0,001	0,000	0,001	1,119	2,290	6,101
P7	2,45	0,002	0,001	0,001	1,912	2,635	7,738
P8	1,643	0,003	0,002	0,001	2,943	3,419	11,330
P9	1,243	0,002	0,002	0,001	2,861	2,552	8,220

Conclusions

It is obvious that the shape of the structure is determining. Pushover analysis is faster than Time History Analysis for both single and multi mode analysis. But in single mode analysis, the irregularities of the structure makes the analysis incorrect (curbs and differences between the height of the columns). So the geometrical shape of the structure must be taken into consideration. Nurtepe Viaduct is an irregular structure because of the curb and the different heights of the columns. In single mode analysis, the short columns are not participating at modal analysis, so the modal participation mass ratio does not satisfy the requirements. So Time History Analysis is used. The differences between the analysis are shown at tables.

Columns: Plastic hinges were occured in both longitudinal and transversal directions at columns according to the time history analysis. The plastic strain values obtained from the plastic rotations were smaller than the limit values. Shear capacity of the colums satisfied the requirements.

Foundations: The soil stress value under the retrofitted spread footing foundations were smaller than the allowable soil stress value. Also the tension area was under 50%. At P3 and P4 axes, the foundations with piles, satisfied the requirements after increasing the height of the footing. At piles, small amount of plastic strain occured but the strain values were smaller than the limit values.

Seismic Buffers: At every abutment and piers, new seismic buffers will be constructed between the beams.

Tension Bars : At every piers, every beam will be connected to each other with tension bars. There should be 3cm gap for thermal expansion.

Expansion Joints : Existing expansion joints will be protected at A and B axes.

Table 9. Spread Foundation results table of Nurtepe Viaduct (Longitudinal Direction)

Axles	Foundation type	Existing Situation			Retrofitted Situation			Allowable soil stress (F.S.: 1.5)
		Dimensions	Ratio of Tension Area	Soil Stress	Dimensions	Ratio of Tension Area	Soil Stress	
		m		kN/m2	m		kN/m2	kN/m2
P1	Spread	8.5x7.5x2 m	80%	3067	14x13x3.2 m	40,38%	1004,6	1013,8
P2	Spread	11x7.5x2 m	60%	1465	14x13x3.2 m	40,38%	949,4	980,7
P3	Pile	12.5x7.5x2.25 m	Pile Foundation					
P4	Pile	12.5x7.5x2.25 m	Pile Foundation					
P5	Spread	11x8.5x2 m	30%	825	14x12.5x3.2 m	28%	945,5	989,33
P6	Spread	11x7.5x2 m	60%	1465	14x13x3.2 m	40,38%	949,4	980,7
P7	Spread	11x7.5x2 m	60%	1465	14x13x3.2 m	40,38%	949,4	980,7
P8	Spread	8.5x7.5x2 m	80%	3067	14x13x3.2 m	40,38%	1004,6	1013,8
P9	Spread	8.5x7.5x2 m	80%	3067	14x13x3.2 m	40,38%	1004,6	1013,8

Table 10. Spread Foundation results table of Nurtepe Viaduct (Transverse Direction)

Axles	Foundation type	Existing Situation			Retrofitted Situation			Allowable soil stress (F.S.: 1.5)
		Dimensions	Ratio of Tension Area	Soil Stress	Dimensions	Ratio of Tension Area	Soil Stress	
		m		kN/m2	m		kN/m2	kN/m2
P1	Spread	8.5x7.5x2 m	56%	1413	14x13x3.2 m	42,85%	1004,6	1013,8
P2	Spread	11x7.5x2 m	56%	1257	14x13x3.2 m	46,42%	949,4	980,7
P3	Pile	12.5x7.5x2.25 m	Pile Foundation					
P4	Pile	12.5x7.5x2.25 m	Pile Foundation					
P5	Spread	11x7.5x2 m	45%	1027	14x12.5x3.2 m	41,07%	945,5	989,33
P6	Spread	11x7.5x2 m	56%	1257	14x13x3.2 m	46,42%	949,4	980,7
P7	Spread	11x7.5x2 m	56%	1257	14x13x3.2 m	46,42%	949,4	980,7
P8	Spread	11x7.5x2 m	56%	1413	14x13x3.2 m	42,85%	1004,6	1013,8
P9	Spread	8.5x7.5x2 m	56%	1413	14x13x3.2 m	42,85%	1004,6	1013,8

Figure 10: Retrofitting of Foundations

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