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Optimal Cost Analysis for Static Load Test on Large Size Reinforced Concrete Piles

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Abstract: **Test loading is the most definitive method of determining load capacity of a pile. Testing a pile to failure provides valuable information to the design engineer and is recommended for load tests performed prior to the foundation design. After execution they confirm a theoretically designed deep foundation. ASTM D-1143-07, Standard Test Method for Piles under Static Axial Compressive Load, is used [1]. This method is applicable to all types of deep foundations that function in a manner similar to piles regardless of their method of installation. This standard provides minimum requirements for testing deep foundations under static axial compressive load.**
Field tests provide the most reliable relationship between the axial loads applied to a deep foundation. A foundation designer may evaluate the test results to determine if, after applying an appropriate factor of safety, the pile or pile group has an ultimate static capacity and a deflection at service load satisfactory to support a specific foundation. The aim of this study is to analyze two type of solution for performing static load test on large size reinforced concrete piles cast in situ. Both types are compered for the advantages and disadvantages that they accommodate. The most effective one is selected and the result of one test is shortly presented. Load Applied by Hydraulic Jack(s) Acting against Anchored Reaction Frame is selected for performing fifteen working load test and two ultimate load test during the construction of 11 bridges on the project "Construction of Replacement Roads and Bridges in Gramsh, Albania".

Keywords: static load test; cost analysis; piles; reaction frame.

I. INTRODUCTION

The static load tests are performed usually on verification of bearing capacity of piles. During the execution of the project "Construction of Replacement Roads and Bridges in Gramsh, Albania" have to be constructed 11 new bridges. The longest bridge is more than then 400m long, 55m high and with the superstructures fragment constructed by two continues steel beams with the typical span 55m. Fifteen working load tests and two ultimate load tests have to be performed during the construction, see Table 1.

TABLE I.

PILE TESTS LIST			
BRIDGE	Number of piles	Working Pile Load Test	Ultimate Pile Load Test
Br - 1	-	-	-
Br - 2	24	2	-
Br - 3	88	3	1
Br - 4	-	-	-
Br - 5	12	1	-
Br - 6	37	2	-
Br - 7	28	2	-
Br-8	18	1	-
Br-9	12	1	-
Br-10	14	1	-
Br - 11	50	2	1
TOTAL	**283**	**15**	**2**

In table nr 2 are presented all the piles with the corresponding load to be tested. The highest value to be used is 1200ton for the ultimate load test on the bridge nr 3 and Pear nr 3.

The load test area defined as:

1. Working pile load tests: the tests carried out on piles that are part of the foundation which is necessary not to compromise the integrity; the maximum load to reach during the test (Pmax) is generally equal to 1.5 times the working load (Qes)[2];

2. Maximum pile load tests: tests carried out on piles, specifically arranged outside the piling, pushed to breaking loads of the pile-soil system or close; the maximum load to be achieved during the test (Pmax) is usually equal to2.5÷3 times the working load (Qes)[2];

TABLE II.

PILE TESTS LOADS LIST							
Nr.	**Bridge Number**	**Pile number per abatement**	**(Qes) (ton)**	**coefficient of test load**	**(Pmax) (ton)**	**pile length (m)**	**LONG. REINFOR.**
	BRIDGE 2						
a	Pier 1	6	477.9	1.5	716.9	12	20 Ø20
b	Pier 2	6	492.2	1.5	738.3	12	20 Ø20
	BRIDGE 3						
a	Pier 3	9	480.0	2.5	1200.0	18	20 Ø25
b	Pier 8	8	425.7	1.5	638.6	15	20 Ø25
	BRIDGE 5						
a	Abutment 1	6	248.2	1.5	372.3	10	20 Ø20
b	Abutment 2	6	248.2	1.5	372.3	10	20 Ø20
7	BRIDGE 6						
a	Pier 1	8	447.2	1.5	670.8	12	20 Ø20
b	Pier 2	9	476.9	1.5	715.3	18	20 Ø25
	BRIDGE 7						
a	Abutment 1	6	237.8	1.5	356.7	10	20 Ø20
b	Pier 2	8	438.3	1.5	657.5	15	20 Ø25
	BRIDGE 8						
a	Abutment 1	6	416.4	1.5	624.6	10	20 Ø20
	BRIDGE 9						
a	Abutment 2	6	257.4	1.5	386.1	10	20 Ø20
	BRIDGE 10				0.0		
a	Pier 1	6	477.9	1.5	716.9	12	20 Ø20
b	Pier 2	8	396.0	1.5	594.0	15	20 Ø25
	BRIDGE 11						
a	Pier 1	8	384.0	1.5	576.0	8	24 Ø25
b	Pier 1	6	475.0	2.5	1187.5	6	20 Ø20

Two are the main problems: first of all selection of the scheme and second one is selection of the procedure. Mostly used scheme for pile tests are:

a. Load Applied by Hydraulic Jack(s) Acting against a Weighted Box or Platform
b. Load Applied by Hydraulic Jack(s) Acting against Anchored Reaction Frame

As per below ,figure 1, a schematic from ASTM D 1143/D 1143M – 07 of a generic test executed using Weighted Box or Platform and Figure 2 anchored reaction frame. In the Figure 3 is presented the plane of the pile to be tested on the Bridge 3 at near pier 3.

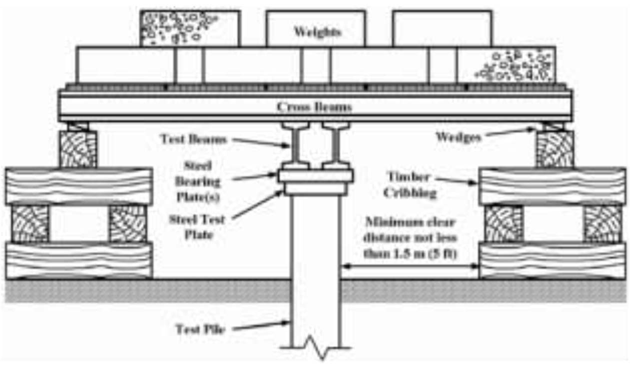

Figure 1. Schematic Hydraulic Jack Acting Against Weighted Box or Platform

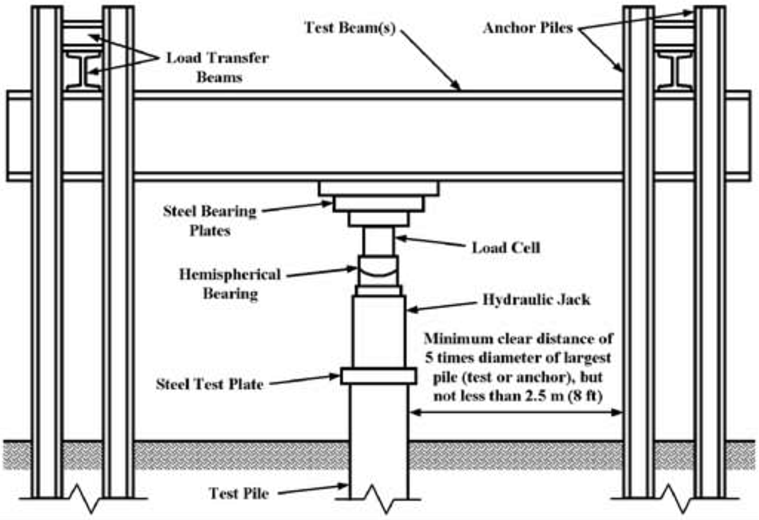

Figure 2. Schematic of Hydraulic Jack Acting Against Anchored Reaction Frame

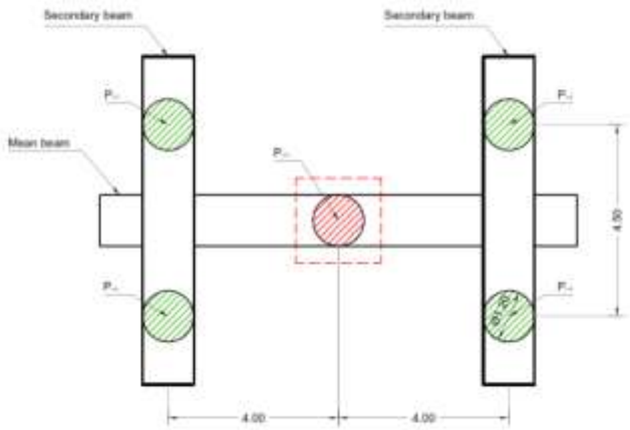

Figure 3. Schematic presentation of the ultimate static test on bridge 3

II. STEEL FRAME DESIGN

Before deciding for which scheme to be used in the project, a cost analyzes is made. First there are made the design of the steel beams to be used for both schemes. We are presenting here only the design of the steel beams for the Load Applied by Hydraulic Jack(s) Acting against Anchored Reaction Frame.

A. Material, scheme, action and section

Structural steel class S-355, fy=355N/mm2, fy=510N/mm2, E=210000 N/mm2

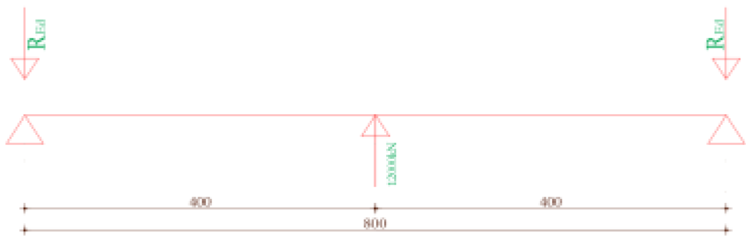

Figure 4. Scheme for main beam

Figure 5. Scheme for secondary beams

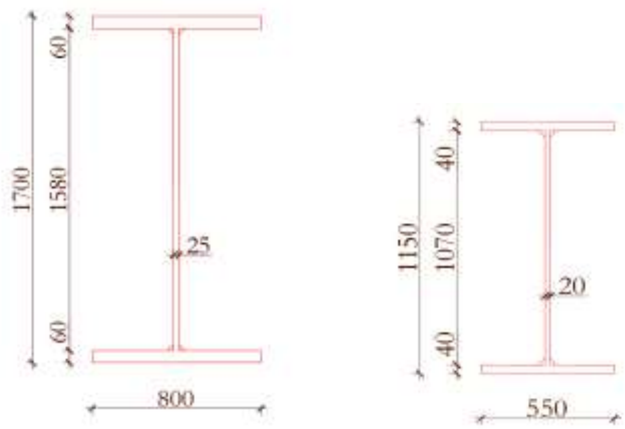

Figure 6. Section for main beam and the secondary beams

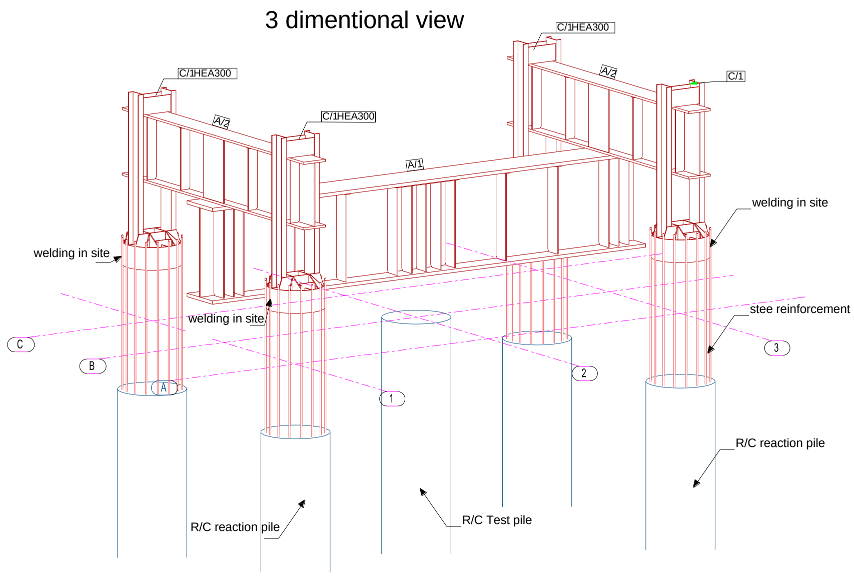

Figure 7. Three dimentional view of the steel frame

B. Design of main Beam

The characteristics of the main beam section are presented on the Table nr 3 below. Only a part of the design calculation is presented here. The same presentation is made also for the secondary steel beams.

TABLE III.

Height of section	h	1700.00	[mm]
Width	b	800.00	[mm]
Web thickness	t_w	25.00	[mm]
Flange thickness	t_f	60.00	[mm]
Radius	r	0.00	[mm]
Weld thickness between flange and web	s	30.00	[mm]

C	Section Classification		
Height(net) between flanges	**h_i**	**1580.00**	**[mm]**
Height(net) between flanges without weld thickness (-2*s)	**d**	**1520.00**	**[mm]**
Area of section	**A**	**1355.0**	**[cm^2]**
Shear resisting area in z	**A_{vz}**	**410.00**	**[cm^2]**
Shear resisting area in y	**A_{vy}**	**960.00**	**[cm^2]**
Momentof inertia ,strong axis	**I_{yy}**	**7279652**	**[cm^4]**
Momentof inertia ,weak axis	**I_{zz}**	**512206**	**[cm^4]**
Radius of gyration strong axis	**i_{yy}**	**73.30**	**[cm]**
Radius of gyration weak axis	**i_{zz}**	**19.44**	**[cm]**
Elastic module resistence ,strong axis	**$W_{el,yy}$**	**85643.0**	**[cm^3]**
Elastic module resistence ,weak axis	**$W_{el,zz}$**	**12805.1**	**[cm^3]**
Plastic module resistence ,strong axis	**$W_{pl,yy}$**	**94322.5**	**[cm^3]**
Plastic module resistence ,weak axis	**$W_{pl,zz}$**	**19446.9**	**[cm^3]**
Torsional moment of inertia	**I_t**	**11984.2**	**[cm^4]**
Warping factor	**I_w**	**3442688000**	**[cm^6]**

Yeld stress of steel Valore di snervamento dell'acciaio		f_y	355	[MPa]
Coefficiente ε	ε=(235/fy)^0.5	ε	0.81	[-]
Classe of web				
Net height of web		c	1520.00	[mm]
Thickness of web		t_w	25.00	[mm]
Height/thickness ratio		c/t_w	60.80	[-]
Class of web from flexure		CLASSE 2		
Class of web from compression		CLASSE 4		
Class of flanges				
half width of flange		c	357.5	[mm]
thickness of flange		t_f	60.00	[mm]
Half widh/thickness ratio		c/t_f	5.96	[-]
Class of flange from flexure		CLASSE 1		

So:

$$M_{cr} = \psi \cdot \frac{\pi}{L_{cr}} \cdot \sqrt{EJ_y \cdot GJ_T} \cdot \sqrt{1 + \left(\frac{\pi}{L_{cr}}\right)^2 \cdot \frac{EJ_\omega}{GJ_T}} \qquad (1)$$

With ψ=1.75 ; L_{cr} =8000mm ;G=80769 N/mm^2 we have

M_{cr}=1.75*3.14/8000*(2.1*10^5* 72796516667*80769*119842059.6)$^{0.5}$ * [1+(3.14/8000)^2 * 2.1*10^5 *3442.68*10^{12}/80769*119842059.6)$^{0.5}$]= 2.47859 E+11 N*mm

λ_{LT} =(355*94322.5*10^3/2.47*10^{11})=0.367 $\lambda_{LT,0}$=0.4

Φ_{LT} =0.5[1+0.76(0.367-0.4)+0.75*0.367^2]=0.538 k_c=0.86

f=1-05(1-0.86)[1-2$(0.367-0.8)^2$]=0.956

$$\chi_{LT} = \frac{1}{f} \cdot \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \beta \cdot \bar{\lambda}_{LT}^2}} \leq \begin{cases} 1,0 \\ \frac{1}{\bar{\lambda}_{LT}^2} \cdot \frac{1}{f} \end{cases} \qquad (2)$$

χ_{LT} =0.983
M_{bRd} = χ_{LT}*Wy*fyk/γ_{M1}=0.983*94322.5*10^3 *355/1.05=31347kN*m
Med= 1.2*12000kN*8/4=28800kN*m 1.2 is an amplification factor for ultimate load, self weight of beam is neglected (on safe side) Ratio =28800/31347=0.918<1 Conclusion: the check is passed.

The characteristic of the secondary beam section are presented on the table below.

TABLE IV.

Height of section	h	1200.00	[mm]
Width	b	450.00	[mm]
Web thickness	t_w	20.00	[mm]
Flange thickness	t_f	40.00	[mm]
Radius	r	0.00	[mm]
Weld thickness between flange and web	s	30.00	[mm]
Height(net) between flanges	h_i	**1120.00**	**[mm]**
Height(net) between flanges without weld thickness (-2*s)	d	**1060.00**	**[mm]**
Area of section	A	**584.0**	**[cm²]**
Shear resisting area in z	A_{vz}	**232.00**	**[cm²]**
Shear resisting area in y	A_{vy}	**360.00**	**[cm²]**
Momentof inertia ,strong axis	I_{yy}	**1445675**	**[cm⁴]**
Momentof inertia ,weak axis	I_{zz}	**60825**	**[cm⁴]**
Radius of gyration strong axis	i_{yy}	**49.75**	**[cm]**
Radius of gyration weak axis	i_{zz}	**10.21**	**[cm]**
Elastic module resistence ,strong axis	$W_{el,yy}$	**24094.6**	**[cm³]**
Elastic module resistence ,weak axis	$W_{el,zz}$	**2703.3**	**[cm³]**
Plastic module resistence ,strong axis	$W_{pl,yy}$	**27152.0**	**[cm³]**
Plastic module resistence ,weak axis	$W_{pl,zz}$	**4162.0**	**[cm³]**
Torsional moment of inertia	I_t	**2158.5**	**[cm⁴]**
Warping factor	I_w	**204363000**	**[cm⁶]**
Yeld stress of steel Valore di snervamento dell'acciaio	f_y	355	[MPa]
Coefficiente ε	ε	0.81	[-]
Classe of web			
Net height of web	c	1060.00	[mm]
Thickness of web	t_w	20.00	[mm]
Height/thickness ratio	c/t_w	53.00	[-]
Class of web from flexure		**CLASSE 1**	
Class of web from compression		**CLASSE 4**	
Class of flanges			
half width of flange	c	185	[mm]
thickness of flange	t_f	40.00	[mm]
Half widh/thickness ratio	c/t_f	4.63	[-]
Class of flange from flexure		**CLASSE 1**	

Based on equation (1) we have:

With ψ=1.75 ; Lcr =4500mm ;G=80769 N/mm2 we have

Mcr=65.66 E+9 N*mm

λLT =0.383 λLT,0=0.4

ΦLT =0.548 kc=0.86

f=0.954

Based on equation (2) we calculate: χLT =0.968

MbRd = χLT*Wy*fyk/γM1=0.968*27152*103 *355/1.05=8888.0kN*m

Med= 1.2*6000kN*4.5/4=8100kN*m 1.2 is an amplification factor for ultimate load ,self weight of beam is neglected (on side safe) Ratio =8100/8888=0.911<1 ok Conclusion: the check is passed.

Additional calculations for shear buckling check are made. Necessary web stiffening are installed in order to fulfill design requirement. Stress and deformation is calculated for the cylindrical element and the steel profiles that are freely connected to the secondary beams. The ultimate loads have the scheme according figure 3. The reaction pile and the tested pile are outside the bridge pier foundation only for the ultimate load test. For the other tests the reaction reinforced concrete piles and the tested piles are working piles. Due to the different type of the geologies and pier foundations, different spans and tested loads are faced. All the representative combinations are studied and the most disadvantage combination is the ultimate load test with the load 1200ton presented, on the figure 3. Steel cylindrical segment are necessary to be connected by welding of the reinforcement steel of the reaction pile. Due to the different length of the working piles serving as reaction piles the steel cylinder element can move over the secondary steel beam.

With this designed and checked frame we will perform all the pile load tests.

III. Costs Comparison

Analysis is firstly made for the option a, Load Applied by Hydraulic Jack(s) Acting against a Weighted Box or Platform. A price breakdown is made for this item. All the equipment, materials, specialists and others measures and equipment necessary to perform the work for the ultimate load test are considered. In the rubric B the steel frame is considered to be used 17 times and the corresponding reduced value is included. The remaining value is deducted from the unit price. The detailed cost is presented on Table V as per below:

TABLE V.

Price breakdown, option a, Load Applied by Hydraulic Jack(s) Acting against a Weighted Box or Platform

A	General	nr	unit	quantity Days	nr*days	price unit (euro)	total value (euro)
1	Auto crane 50t	2	day	4	8	244.3	1954.28571
2	Trailer	2	day	4	8	428.6	3428.57143
3	Hydraulic jack	4	day	4	16	1250	20000
4	Data register and rapport preparation	1	day	4	4	500	2000
5	Welder specialist	2	day	4	8	30	240
6	Skilled worker	2	day	4	8	20	160
7	Foreman	1	day	4	4	30	120
8	Technician	1	day	4	4	35	140
9	Engineer	1	day	4	4	45	180
10	Safety officer	1	day	4	4	35	140
				Sub total			28362.9
11	Others (preparatory works, safety measures etc.)			5%			1418.14
				Total A			**29,781.00**
B	**Steel frame**		**unit**	**quantity**	**nr of time to be used**	**unit price (euro)**	
1	Steel Frame including materials, cutting and welding.		kg	18000	17	1058.82	
2	Corresponding value to one pile test for depreciation				1058.82	1.4	1482.4
				Total B			**1,482.35**
C	**Weighted Box+ test pile**			**unit**	**quantity**	**unit price**	**total**
1	Excavation			ml	18	35	630
2	Concrete c 20/25			m3	560	5	2800
3	Reinforcement			kg	2160	0.9	1944
				Total B			**5374**
				Total A +B +C			**36,637.35**
D	Over heads	10%					3663.7
E	Profits	15%					5495.6
	Total price A +B+C+D+E						**45,796.69**

In the Table VI is presented the second option b, Load Applied by Hydraulic Jack(s) Acting against Anchored Reaction Frame. The designed frame will be used 17 times and only the corresponding portion will be considered in this test.

The difference is clear from case a, 45,796 euro to 30,545euro for case b. The higher value of the case a, is mostly dedicated to the duration of the test and cost of the transport. Because the 560m3 concrete blocks are needed only for the ultimate test the expected difference for the other tests is expected to be less. Anyway the case b is definitely much more economical and this option is selected to perform the tests on the project. These prices are based on Albanian construction market and on the time that this article is prepared. On other country and time, other situation normally is possible.

TABLE VI.

Price breakdown, option b, Load Applied by Hydraulic Jack(s) Acting against Anchored Reaction Frame

A	General	nr	unit	quantity Days	nr*days	price unit (	total value (euro)
1	Auto crane 50t	1	day	1	1	244.3	244.3
2	Trailer	1	day	1	1	428.6	428.6
3	Hydraulic jack	4	day	1	4	1250	5000
4	Data register and rapport preparation	1	day	2	2	500	1000
5	Welder specialist	3	day	2	6	30	180
6	Skilled worker	2	day	2	4	20	80
7	Foreman	1	day	2	2	30	60
8	Technician	1	day	2	2	35	70
9	Engineer	1	day	2	2	45	90
10	Safety officer	1	day	2	2	35	70
				Sub total			7222.9
11	Others (preparatory works, safety measures etc.)			5%			361.14
				Total A			**7,584.00**
B	**Steel frame**		**unit**	**quantity**	**nr of time to be used**	**unit price (euro)**	
1	Steel Frame including materials, cutting and welding.		kg	22000	17	1294.12	
2	Corresponding value to one pile test for depreciation				1294.12	1.4	1811.8
				Total B			**1,811.76**
C	**Reaction pile + test pile**			**unit**	**quantity**	**unit price**	**total**
1	Excavation			ml	90	35	3150
2	Concrete c 20/25			m3	101.736	50	5086.8
3	Reinforcement			kg	7560	0.9	6804
				Total B			**15040.8**
				Total A +B +C			**24,436.56**
D	Over heads	10%					2443.7
E	Profits	15%					3665.5
	Total price A +B+C+D+E						**30,545.71**

Based on the number of the tests to be performed, the restricted time for the execution and the high value of the load test, it was selected the scheme b presented on the figure nr 2.

IV. Static Load Test Methode

The test load is placed in such a way. in order we could assure a uniform pressure over the pile and at the same time the settlement readings are taken directly on the piles.

Static load tests are performed during the test phase of each contract to verify the design assumptions and load-carrying capacity of the piles.

Static loads were applied and maintained using four hydraulic jacks and were measured with load cells. Reaction to the jack load is provided by the principal steel beam, supported on two additional steel beams that are connected to 4 anchor concrete piles. Pile head deflections was measured with 3 dial gauges at 120° distance on an independent 'frame' to measure the pile head displacement. For all measurement devices, certificates of calibration are taken for the accuracy of the results and standard requirements.

The procedure for loading shall be as follows:
1. The test load will be measured within an accuracy of two (2) percent. Settlements will be measured within an accuracy of one-tenth (0.1) millimetres.
2. Unless otherwise directed the test load will be applied in the following manner:
(1) to the working load (as described on the appropriate plans) by six equal increments;
(2) removal of all the (3) to one-and-one-half (1.5) times the working load by two equal increments up to the

working load and thereafter by six equal increments;
(4) removal of all the load.
3. The load after each increment shall be kept constant until the rate of settlement does not exceed twenty-five hundredths (0.25) millimeters per hour.
4. The amount of settlement shall be recorded before the next increase of load.
According the design requirement, the settlement of the pile under the test load shall not be greater than fifteen (15) millimeters, and the recovery of the pile after the subsequent removal of the test load shall not be less than five (5) millimeters.

The load sequence has been carried out following two loading-unloading cycles in order to reach during the first cycle 150% of the Qes and during the second cycle 250% of the Qes where Qes is the maximum working load for testing pile.

Figure 8. General layout installation of steel frame during load test on the bridge 3, piles nr 3

Figure 9. Installation of 4 hydraulic jacks on the bridge 3, piles nr 3

Here below in figure 7 is presentet only the graph of the test results are presented. The reaction load - settlement of the pile is clear for the two cyclic progressive load increasing loading. The compliance of the results is confirmed from the designer and the next test is prepared to commence.

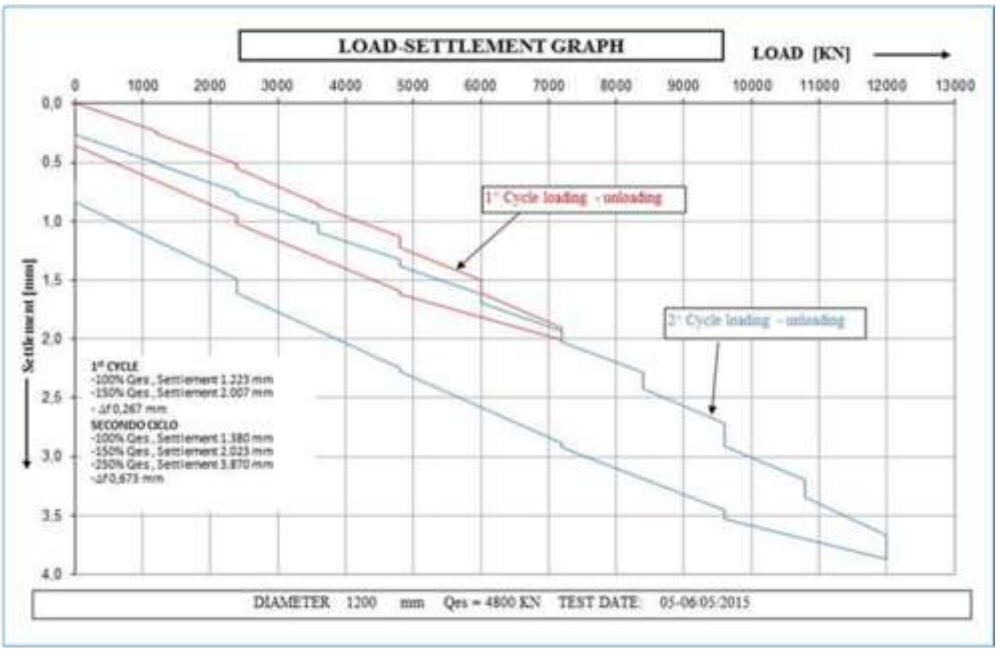

Figure 10. Load –settlement graph

V. CONCLUSIONS

The static load tests on piles are known as expensive one. As a consequence Engineers, Contractors, Owners are interested to reduce the costs on performing such tests. In this case study, it was with interest to choose the optimal cost of two type of known static load test on large piles. The short conclusions are the followings:

- Load Applied by Hydraulic Jacks Acting against Anchored Reaction Frame are more cost effective in case of large test loads on cast in situ piles.
- The site is much clear and less area is required to perform the test.
- In addition the time for performing the test is much shorter than the case with Load Applied by Hydraulic Jacks Acting against a Weighted Box or Platform
- If the tender documents provide detailed specifications regarding the methodology used to perform the static load test on high dimensions piles, then it should be possible for employers to save more money.

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