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IDENTIFICATION OF SOIL-STRUCTURE INTERACTION EFFECTS BASED ON GEODETIC MONITORING OF A RAILWAY BRIDGE

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ABSTRACT: The monitoring of bridges using geodetic methodologies permits the direct measurement of displacements and potential identification of effects of soil-structure interaction. In this study the response of the historical Gorgopotamos railway (Central Greece) has been measured using a Robotic Total Station (RTS) during the passage of trains on different times of the year and under various soil conditions. The measurements revealed that the initial impact response of the deck to the train loading presents differences which seem to correlate with the differences in the moisture content of the bridge foundation ground.

KEY WORDS: RTS, Geodetic Monitoring, Railway Bridge, Deflection

1 INTRODUCTION

The response of structures to dynamic loads is to a certain degree influenced by the interaction between structure, soil and foundations in general. Although the soil-structure interaction is always present to some degree, it is generally assumed that the motion at the structure does not influence the motion of the foundation [1]. However, when the soil-structure interaction becomes significant, this assumption is not true due to the feedback from the structure to the foundation and the surrounding soil medium [2]. Thus, the soil-structure interaction influences the motion of the structure due to the soil motion, which is expressed through the displacement of the structure and its modal frequencies [3].

Furthermore, there is a large interest in monitoring of structures response based on the modern geodetic techniques, GPS and Robotic Total Station (RTS). Many studies have been made, which proved that GPS and RTS can be sensitive and accurate enough for the monitoring of rigid structures with modal frequencies larger than 2-3Hz [4,5].

In this paper, we present an extraordinary case of historical railway bridge in which we measured the response of the bridge when trains were passing in different environmental conditions using a RTS. The RTS technique was

selected due to its high accuracy (of 1mm level) for modal frequencies up to 5-6Hz. The aim of the study is to detect the influence of the soil-structure interaction on the response of the bridge and how this is expressed on the bridge displacement, through the RTS recordings.
Finally, from this study was revealed that when the soil of the bridge foundation, corresponding to marls, was saturated, the passage of heavy trains was causing an atypical displacement of larger amplitude than the one caused under usual conditions of unsaturated soil. In this study a preliminary analysis of the RTS displacement time series and their correlation with the soil condition are presented.

2 THE GORGOPOTAMOS RAILWAY BRIDGE

The Gorgopotamos Railway Bridge is located about 150km northwest of Athens, in central Greece, and was constructed in 1905. The bridge was destroyed and rebuilt twice during Second World War (Fig.1). The first destruction was in 1942 and after its reconstruction in 1943, it was destroyed again in 1944. The bridge was reconstructed again in 1948 and since then is still in use.
The bridge has total length of 211m and 32m maximum height. It is curved in plan, consisting of seven sub-linear spans of approximate length of ~30m, which are supported by six pylons. The bridge is a composite structure with a truss deck, two steel pylons (M_1, M_2) and four masonry pylons (M_3-M_6); see Figure 1.
The foundations of the bridge are on marls causing a long-term (static) instability, and for this reason drainage works had been made in the near past. The instability of the bridge seemed to affect the passage of the train, which are usually forced to reduce speed.

3 RTS – PRINCIPLES AND METHODOLOGY

RTS is the evolution of the common total station. The instrument emits a ray which is reflected on a reflector fixed on the specific point is received back and analysed, and the instantaneous 3-D polar coordinates of the reflector are computed in a pre-defined coordinate system. RTS is also equipped with a servo-mechanism and an automatic target recognition device, permitting to lock on a specific target, follow its movement and record its coordinates with a rate higher than 5-6 Hz.

Basic requirements for accurate measurements are the visibility of the reflector, the absence of perturbations of the atmosphere along the raypath and the use of a high-quality prismatic reflector. Further details about the instrument and the RTS monitoring are described in [6].

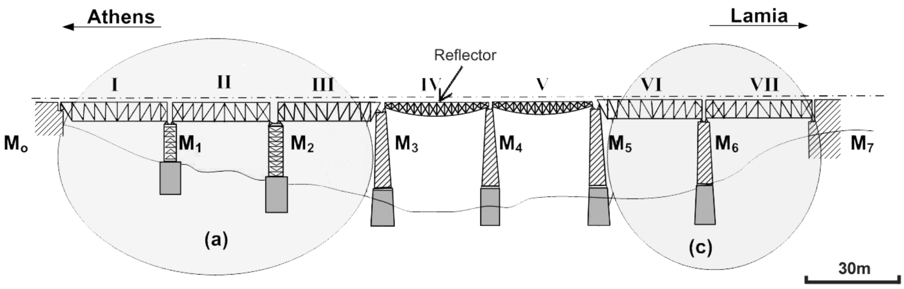

Figure 1. The Gorgopotamos Railway Bridge with area a and c indicating the destroyed parts of the Bridge in 1942 and 1944, respectively. Also the reflector position discussed in this article is indicated.

4 METHODOLOGY

The aim of this study was to estimate the deflection of the bridge caused by passing trains, of similar type and size, and try to detect potential influence of the soil condition to the bridge response. For this reason we focused on excitation on the excitation of the bridge of similar passing trains for two different times in the same year.

We focused on the midspan of an opening, where the maximum displacement of the bridge was expected and corresponding to the most saturated soil of the bridge foundation. The measurements were made before, during and after the passing trains. The measurement noise (uncertainty) was estimated based on the measurements of the intervals before and after the train passage, corresponding to intervals of no bridge excitation. Measurements during passing trains, corresponding to the train excitation intervals, were compared with the measurement noise, and if the signal of the excitation interval was larger than the noise, measurements corresponded to real displacements.

Finally, based on a simple low-frequency filter (e.g. moving average) we separated the semi-static (low-frequency) from the dynamic (high-frequency) displacement of the structure and we estimated the corresponding amplitude.

5 FIELD MEASUREMENTS

Our study was focused on measurements of the displacements of point at the midspan between pylons M_3-M_4, through which the Gorgopotamos river is passing, causing the saturation of the foundation soil. This point was marked by a high-accuracy prismatic AGA-type reflector, fixed on the metallic bridge handrail. A Leica TCA 1201 RTS was set on stable ground at a distance of circa

Figure 2. The Gorgopotamos Railway Bridge and in the foreground the RTS used for the measurements focusing on reflector. An inset shows the prismatic reflector and on top of it the antenna of a GPS, used as a chronograph.

150m from the reflectors, at a point permitting unobstructed view of the reflectors (Fig.2). Details on the use and the limitations of this instrument, and the solutions adopted to obtain high-accuracy data, useful for structural analysis are described in [6] and [7].
Measurements during the passage of several trains were made. In this study we focus on the recordings of two passing train cases: i) a 8-wagon freight train on 12.04.06 (case 1) and ii) a 7-wagon freight train on 12.07.06 (case 2). Thus, we compared the response of the bridge in the passage of two similar trains, in April and July, where the soil conditions were different; in April the marls are saturated, while in July they are practically dry.

6 DATA ANALYSIS

Using a common linear transformation [6,7,8] the recorded coordinates relative to a rather arbitrary system were transformed into coordinate system consistent with the one of the bridge, where the y-axis is tangent to the railway at the observation point and x-axis normal to it. Then the mean value of the recordings from the intervals before and after the passing train was subtracted from each instantaneous coordinate. Thus three time series describing the apparent displacements along the longitudinal, lateral and vertical were obtained.
The time interval of the passing train was defined by combining the records of the chronographer, the GPS records and the RTS records. It was identified the time the train entered and left the bridge (solid lines 1 and 4, Fig.3) and the time interval the train was passing in front of the target (dotted lines 2 and 3, Fig.3).
The measurement noise was estimated based on the data from the intervals

before and after the passing train corresponding to no excitation interval. The data formed zones of amplitude ±1mm expressing the noise level of measurements. This amplitude was smaller than that defined from experiments, ±2mm [7], which, was however adopted as a pessimistic estimate.

In general, the time series of the longitudinal and lateral axes appear lower signal than the noise level, and hence expressed only measurement noise, while the signal of the vertical axis reached the amplitude of 6mm and hence they reflected real displacement of the bridge due to the train excitation.

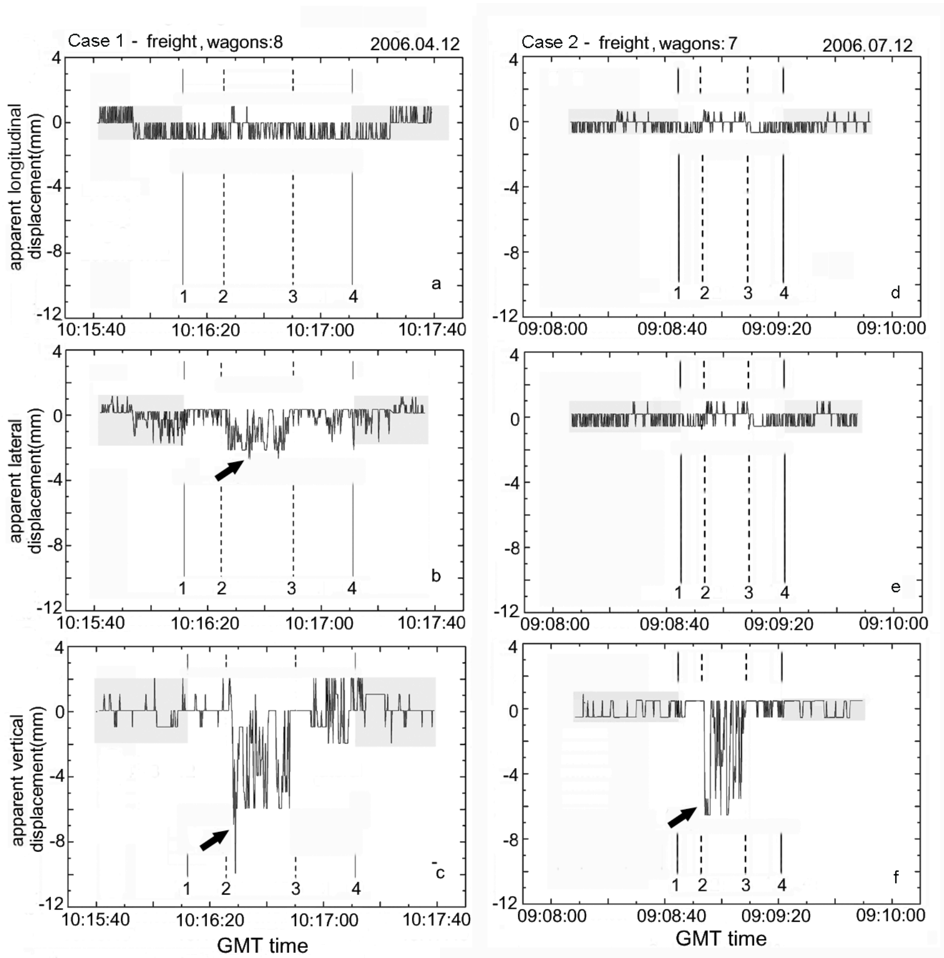

Figure 3. The RTS displacement time series of the three components (longitudinal, lateral, vertical) for the two examined cases. The signal of the lateral (a,d) and longitudinal (b,e) components are close to the noise level, while the vertical component (c,f) is above the noise level expressing displacement. The train lines 1 and 4 indicate the entrance and exit of the train from the bridge and 2 and 3 the passage in front of the target.

Finally, the moving average filter was used for the separation of the semi-static and the dynamic displacement of the two vertical displacement time series. For these time series we used moving average filter of step 21 and overlap 20 [10] and the derived low-frequency (semi-static) time series was subtracted by the initial one, resulting finally to the high-frequency time series (dynamic; Fig. 4).

7 ANALYSIS OF DEFLECTIONS

From the derived semi-static and dynamic displacement time series of the vertical components of the two examined cases (Fig. 4), it was estimated the mean semi-static and dynamic displacement. The semi-static displacement has similar trapezoid pattern for both cases of amplitude ±3.5 and 4mm, while the dynamic displacement express an oscillation of amplitude ±3-4mm. The latter agrees with the typical deformation of railway bridge during the train passage [10]. However, for the case 1 (April) is observed an additional pulse response in the beginning of the excitation, when the first wagon is entering the surveyed opening, reaching the amplitude of 10mm, double the amplitude of the dynamic displacement. This pulse response is not observed in the case 2 (July). Furthermore, increased lateral displacement in the case 1 is also observed. Thus, it is evident of atypical response of the bridge in the case 1 (April) and indicates that the response of the bridge is less rigid and typical in April than July. The latter can be attributed mainly to the differentiation of the structure response due to the saturation of the marls during April.

8 CONCLUSIONS

The output of this study is that the RTS monitoring was not only efficient for the monitoring of the historical Gorgopotamos railway bridge, but even for the identification of the soil-structure interaction. Based on RTS records and simple analysis techniques was possible the identification of the different behavior of the bridge for the two time periods in the year.

It was shown that for the similar excitation (size and train type), the bridge appeared an atypical response (initial extreme pulse response) and lower rigidity (larger lateral displacement) during April (case 1), relatively to July (case 2). The main difference between the two examined periods is the soil condition, as during April the marls are expected to be saturated, which seems to weaken the bridge response.

Thus, the current study shows that the geodetic techniques are reliable and accurate not only for the monitoring of the bridge response but even for the identification of potential effect of soil-structure interaction.

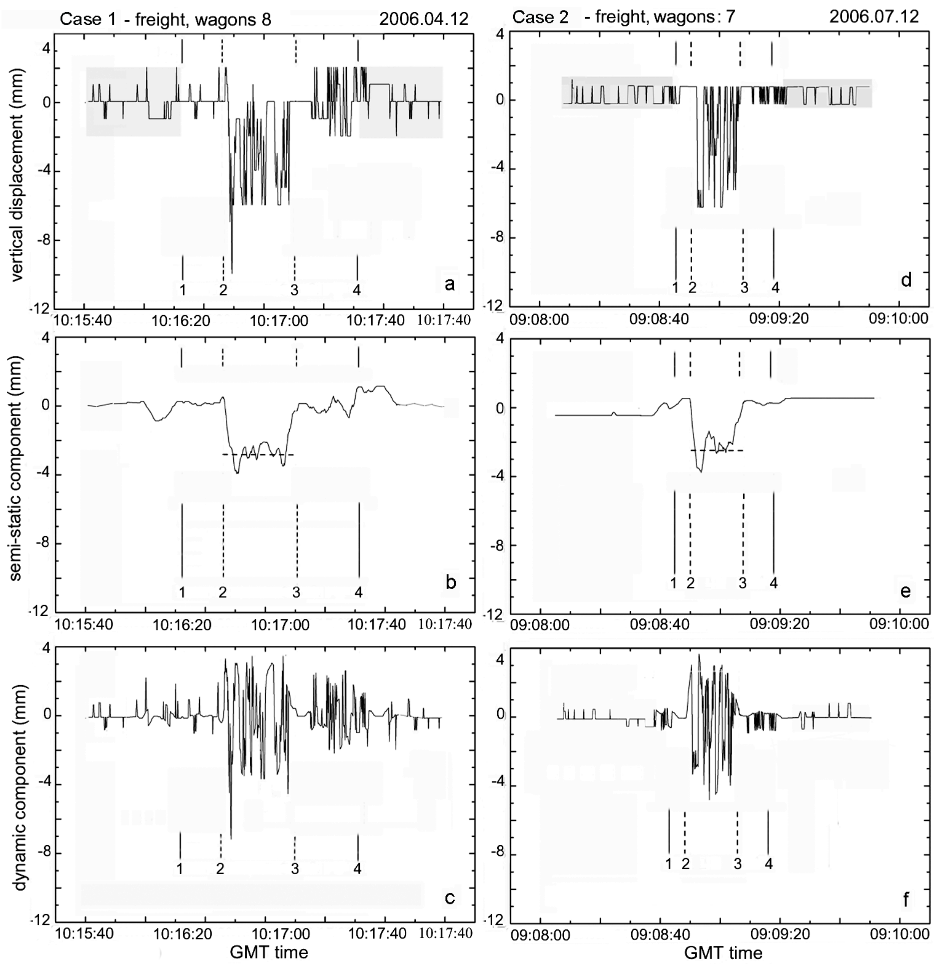

Figure 4. The decomposition of the apparent vertical displacement (a,d) into low-frequency (b,e) and high-frequency (c,f) components, expressing the semi-static and dynamic displacement of the two cases, respectively. The dynamic displacement of case 1 appears a pulse response in the beginning of the oscillation, which makes the response atypical.

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