# TURKEY – ANATOLIAN MOTORWAY RETROFITTING OF VIADUCT 1

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## ABSTRACT

This is to illustrate the design activities and works which turned out to be necessary for Viaduct 1, already built before the earthquake of 1999 which seriously damaged the area where it is located and caused so many deaths among the population.

Even though earthquake acceleration values reached twice the original design values, the 2,400 double-way viaduct structure stood up although its deck and supporting structures were seriously damaged and required retrofitting actions.

The Client asked for more severe design parameters, due to frequent earthquake activities in the area because of the tectonic impact of the two continents and of the secondary branch of the Anatolian fault crossing the viaduct.

The solution worked out by designers and approved by the Client provided for a "simple" change in the deck-bearing system: so the structure support system was changed from a span on simple bearings to a continuous span on seismic bearings (two bearings per each pier cap) allowing displacement of up to ± 600 mm. Substantially, the deck had to be brought back to its original position by shifting it longitudinally by about 110 cm and transversally by about 50 cm, lifting it by about 80 cm thus providing room for positioning the new bearings allowing the structure to swivel in the event of shakes of any magnitude and to set back to its original position after the earthquake.

The intensity of the forces being considered required special equipment which has been specifically designed and manufactured. Strict safety procedures have been adopted during the execution of the works in order to safeguard worker's life and the equipment integrity, due to the conditions of instability of the structure and to the risks connected therewith.

The whole work took 34 months to be completed, thanks to the technicians' and workers' professionalism, who fully met the expectations.

Nowadays, the viaduct, after completion of such section, is ready for commissioning thus allowing to directly link the cities of Ankara and Istanbul.

# 1. INTRODUCTION

During the last few years, we have more and more frequently gone through disastrous events caused by various extreme atmospheric conditions, which caused serious damage to infrastructure but, above all, took a heavy toll of lives.

## 1.1. The Fact

Also in Turkey, where we have been working for several years now, we helplessly experienced, in 1999, the immense force of nature which was unleashed by two earthquakes: the first one, on the 17th of August, in the area of Kocaeli (Izmit) which caused 30,000 victims and 150,000 homeless, and the second one, on the 12th of November same year, with a magnitude of 7.2 on Richter scale, which caused 20,000 victims, the epicentre of which was located in the proximity of our sites, 12 km away from Viaduct 1, and with a PGA (Peak Ground Acceleration) of 0.8 g, as measured by a seismographic station near Bolu.

## 1.2. The Structure

This viaduct, approximately 2,400 m long, had just been completed as part of stretch 2 of the Anatolian Motorway Gümüşova-Gerede, between Istanbul and Ankara, and the structure was caused to undergo a non-scheduled full scale test, since it was located within the area where the earthquake proved to be more severe. In fact, at two thirds of the viaduct, the seismic event had caused a lateral fault slip toward NE-SW. The viaduct had been designed assuming, as seismic datum, an effective ground acceleration (EGA) amounting to 0.4 g, in agreement with AASHTO recommendations in force at that time (edition 1989), such parameters relating to an earthquake with a return period of 500 years.

**Figure 1** - Viaduct 1

## 1.2. The Problem

After a first overexcitement reaction, it was verified that the viaduct, even though seriously damaged, was still standing despite some piers, because of the fault slip, the ground had been displaced from original position by 100-120 cm and some spans were hanging in space out of the bearing surface on the pier cap, supported exclusively by the reinforcing rods and by the concrete of the slab joining the deck sections.

Still nowadays, it is may be the sole example of a structure crossing an active fault and having survived a severe seismic event and which has successfully endured a tremendous shake combined with a physical displacement of the main structures without undergoing definite damage which would have compromised its recovery, thus deserving ENR – Special Advertising Section acknowledgement as "Best Projects 1999".

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A Strong Bridge

Post-Earthquake Analysis

Editorial note:

**Figure 2** – ENR page

## 1.3. The Solution

Had it been already operational and open to traffic, there would not have been any additional victim, and this is the purpose of accurate designs and of carrying out the construction activity according to quality and state-of-the-art rules.

After living the first days following the seismic event in dread of additional violent shakes which would have worsened the already insecure stability conditions, not only due to the inevitable seismic swarm, various experts were contacted in order to decide what to do and, as soon as the news about this viaduct, miraculously still standing, began to spread among the experts in this sector, a multitude of technicians started coming from all over the world to examine more closely such an example of unique work. After hearing a long series of advices, the design for the rehabilitation and securement of the viaduct was entrusted to Prof. G.M. Calvi of the University of Pavia (Italy) and to M.Y.N. Priestley, professor emeritus of the University of California – San Diego who, on the basis of their professionalism and their several recent past accomplishments, studied how to secure the viaduct and to make it meet more demanding parameters in order to better withstand possible additional seismic events.

This viaduct, the operational and construction design of which was drawn up by Mr. Paolo Versace, presently working for Technital (Verona – Italy), but who worked also as our designer in connection with the structures of already operating motorway sections, together with the advisers Studio Macchi of Milan, for conceiving and defining the structure of the works, and Prof. Vincenzo Pane of the University of Perugia, for foundations, is constituted of two separate and independent 17.50 meter-wide roadways with 7 pre-stressed 36,80 meter-long beams per each span simply supported by a 10-span continuous on-site-cast slab.

All the beams, which were laid down on multi-directional POT bearings manufactured by FIP could, under normal conditions, freely slide on burnished stainless steel plates for 32 cm, had a maximum plastic field of 48 cm and were locked by special dissipators named EDU, standing for Energy Dissipation Units, manufactured by ALGA, which would dissipate, thanks to the elasto-plastic ductility of its metal elements, both thermal stress and part of the energy produced by the movement of the deck in case of earthquake, thus reducing the stress on both the piers and the foundations.

Furthermore, in order to safeguard the structure from possible collapse of the deck, according to AASHTO recommendations, the deck sections were anchored at the position of the joints, in this case every 400 meters, to a reinforced concrete block of the pier cap by using strands.

Thanks to such devices, the structure was able to dissipate the energy produced, but not enough so as to prevent concrete and such devices from being damaged, also due to the fact that the overall movement caused by the quake and by the fault was more than double the design's.

After experiencing such an upheaval, the accurate verification of each element of the structure began by investigating possible damage to piles, foundations plinths, piers and pier caps, abutments and deck sections.

Fortunately, the damage suffered by only some of the piles was insignificant and some new piles were driven around the edge of some foundations plinths, and the reinforcement bars of the foundation plinths themselves were re-connected with the concrete structure by new casting and by enlarging the base, while none of the piers suffered any crack or damage; only at the position where the viaduct crosses the fault, a 3° tilting of some piers was found and redressed by lifting the deck, thus proving that all structural deflections were within the elastic field.

**Figure 4 –** Some damages

The outcome of such analysis resulted in the adaptation of the structure to the new seismic parameters demanded by the Client: return period = 2000 years corresponding to a PGA of 0.8 g and consideration of the "near field effect" according to AASHTO seismic standards as being defined in 2001, as well as adoption of new design assumptions based on the experience accrued in other countries, above all in the United States, where the improvement of the structures of most of the bridges and viaducts to withstand more severe quakes has been going on for some years now.

"Retrofitting and Strengthening" consists in using existing structures, clearly after structural verification, and adapting them to the new and more demanding anti-seismic requirements.

The solution devised by the designers and approved by Client "simply" changed the deck-bearings system: the simple deck-on-bearings scheme was changed into a continuous deck on "seismic bearings" (two per each pier cap) allowing for movements up to +/- 900 mm in the area where the viaduct crosses the fault.

The longitudinal continuity of existing deck sections was achieved by using a rigid transverse post-compressed diaphragm, cast in-situ and embedding the ends of the beams constituting the two adjacent deck sections.

## 2. THE RETROFITTING WORK

Once the final "retrofitting" design was drawn up and approved, the quest for companies specialized in such delicate activities involving the deck was started by promoting a tender procedure. The works were subcontracted to Freyssinet – Terra Armata S.r.l. which, in collaboration with its parent company Freyssinet International, carried out its activity for a period of 34 months, from Sept. 2002 until July 2005 showing a high level of skilfulness, organization, professionalism and ability.

The changes involved the re-positioning of the deck, both transversally and longitudinally, at a position 80 cm higher than the original design, in order to allow the installation of new spherical bearings manufactured by E.P.S. (Earthquake Protection Systems, Inc.) of Richmond – California, called "Friction Pendulum Isolation Bearings", anchored to the pier cap and embedded in the new purposely manufactured post-stressed beam, the so-called diaphragm beam, representing the cross-beam of the deck and enclosing the 7 pre-stressed reinforced concreted beams of the deck itself.

The most delicate and complex operation was lifting the ten continuous decks, the so-called "*segment*", already positioned at a maximum altitude of 50 m, displacing it so as to transversally and longitudinally reposition the same at the centre of the pier caps: it should be noted that the weight of each deck section between two pier caps including the seven beams and the slab is of approximately 1,400 tons. The hoisting equipment and the special hydraulic jacks were designed and manufactured by Freyssinet itself, which took care of fine-tuning also the synchronized system for the simultaneous and co-ordinated displacement of the segment, that is to say the 10 deck sections.

**Figure 5 –** Retrofitting work

## 3. CONCLUSIONS

Nowadays, the recovery has been successfully completed and Viaduct 1, fully restored, is ready to confront its new life and withstand the intense traffic which shall go through this crucial link between Istanbul and Ankara.

For the successful completion of these works, which have been performed without any major injury to the workers, special thanks must be given to all those who collaborated at any title in the execution of such works, from designers to suppliers, from subcontractors to workers who have been coming next after another for all these years, and took part in the full recovery and completion the same and made it ready for service.

**Figure 6 –** Final work

**DATA SHEET PROJECT OF VIADUCT 1:**

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| Client: | **MINISTRY OF PUBLIC WORKS AND SETTLEMENT GENERAL DIRECTORATE HIGHWAYS** |
| Engineer: | **YUKSEL PROJE AS – Ankara (TR)** |
| Main Contractor: | **ASTALDI Spa - ROMA** |
| Designer: | **TECHNITAL Spa – VERONA – STUDIO MACCHI - MILANO** |
| Retrofitting: | **STUDIO CALVI – PAVIA, Prof. N. Priestley** |
| SubContractor Retrofitting: | **FREYSSINET TERRA ARMATA Srl - ROMA** |
| New Bearings: | **EPS – California (USA)** |