BACK-ANALYSIS OF A LANDSLIDE IN OVERCONSOLIDATED TERTIARY CLAYS OF THE GUADALQUIVIR RIVER VALLEY (SPAIN)

ANALYSE RETROSPECTIVE DES GLISSEMENTS DE TERRAIN DANS LES ARGILES TERTIAIRES SURCONSOLIDEES DE LA VALLEE DU GUADALQUIVIR (ESPAGNE)

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SYNOPSIS

It is described a landslide which took place in Almodovar del Rio (Cordoba,Spain), affecting, during the construction, the platform of the high speed train connecting Madrid and Sevilla.

The origin and causes of the landslide are investigated. Its morphology and kinematics are very typical of the overconsolidated blue clays of the Guadalquivir river valley. The site investigations and the back-analysis after the landslide explained the progressive failures, both in plan and in transversal section, and the poor geotechnical properties of this geological formations. The peak or the residual, drained and undrained shear strenght are established.

INTRODUCTION

Between Cordoba and Sevilla, near the hill where is situated the village of Almodovar del Rio, the tracks of the old railway line (ORL) joint the new line for the high speed train (HST), and both lines go near and parallel to the banks of the Guadalquivir river.

The typical transversal section of the slope where both lines are situated is represented in the fig.1. The HST platform, after crossing the Almodovar hill in tunnel, continues on a fill of variable height, with a maximum of about 9 m. There exists two retaining walls, one separating the HST and ORL lines, and the second between the ORL and the river.

On March 13, 1991, during the construction of the HST line, a landslide affected the two railway tracks. The previous days to the slide important rains fall in the region. The slope movements began with the typical symptons of instability, such as fissures and cracks in the soil above the railway. Settlement of both tracks were observed in a lenght of 130 m. Finally, on the mentioned date, a sudden and quick slide interrupted the traffic in the ORL line and cutted the track of the new line. (fig 2)

It is interesting to emphasize the following aspects of the landslide:

a) In plan (fig 3), the limits of the movilized soil and rock draw a long shell of the mentioned lenght in the direction of the river bank, and a width of about 60 m. in the normal direction. The height of the slide between the head and the level of the river was 20 m.

b) The central part of the old wall, between the ORL and the river, mantains its integrity in a distance of 95 m.with some moderate cracking. It was displaced about 12 m. in horizontal. The settlement of the crown of the wall was very moderate, with a máximum of 50 cm. The tilting of the wall face was also very light.

c) The new wall between both tracks was displaced in a similar way and distance, but with some cracking and inclination.

d) The river bank was displaced also in a distance of 11 m.

The fig.3 reflects the direction and the general morphology of the main slide and subsidiary movements deduced of the site investigation which follows.

GENERAL GEOLOGIC AND GEOTECHNIC ASPECTS

More than 30 mechanical borings were performed to have a knowledge as good as possible of the geologic configuration of the slope. The substratum is composed of paleozoic shales, which dip almost vertically and oriented in normal direction to the slope surface. Upon the shales it is found the strata of blue miocene overconsolidated clays, typical in the basin of the Guadalquivir river. Locally are called "blue marls". Above the clays, slope debris, coluvium, aluvium and man-made fills were present in very irregular disposition. The phreatic level, after the landslide, was about 1 to 4 m.above the blue marls strata.

The blue marls present a variable plasticity and consistency. The Liquid Limit varies between 40 and 85%; the dry specific weight between 1350 and 1750 daN/m^3 . Frequently show shear zones with slikensides, pointing towards ancient shear local or general displacements, without any specific orientation.

The transversal section of the blue marls has locally the shape of a horn-bull, with the point in the upper part of the slope, and a base 5-8 m.thick under the ORL line and river bottom (fig.1). Under the fill of the HST tracks the contactc between blue marls and shales has a mean dipping angle towards the river of about 29°. Under the ORL line this contact is almost horizontal.

The site investigation revealed that the zone affected by the landslide coincided exactly with the zone in which the borings had detected the presence of blue marls. By this reason it was clearly demonstrated that the main motor of the slide was the poor shear strenght of the blue marls, not sufficient to counteract the shear stress imposed by the man-made HST fills.

KINEMATICS OF THE LANDSLIDE

The blue marls have originated many problems in this region, in relation with the stability of slopes. In most cases the landslides observed and studied have a similar morphology and kinematics. In a schematic way (fig 4), two zones or two wedges can be clearly distinguised in a transversal section. The upper wedge is the first to suffer and to show the signs of the instability. It is deformed in very different ways and magnitude, depending on the local stratigraphic disposition of the soils which cover the blue marls

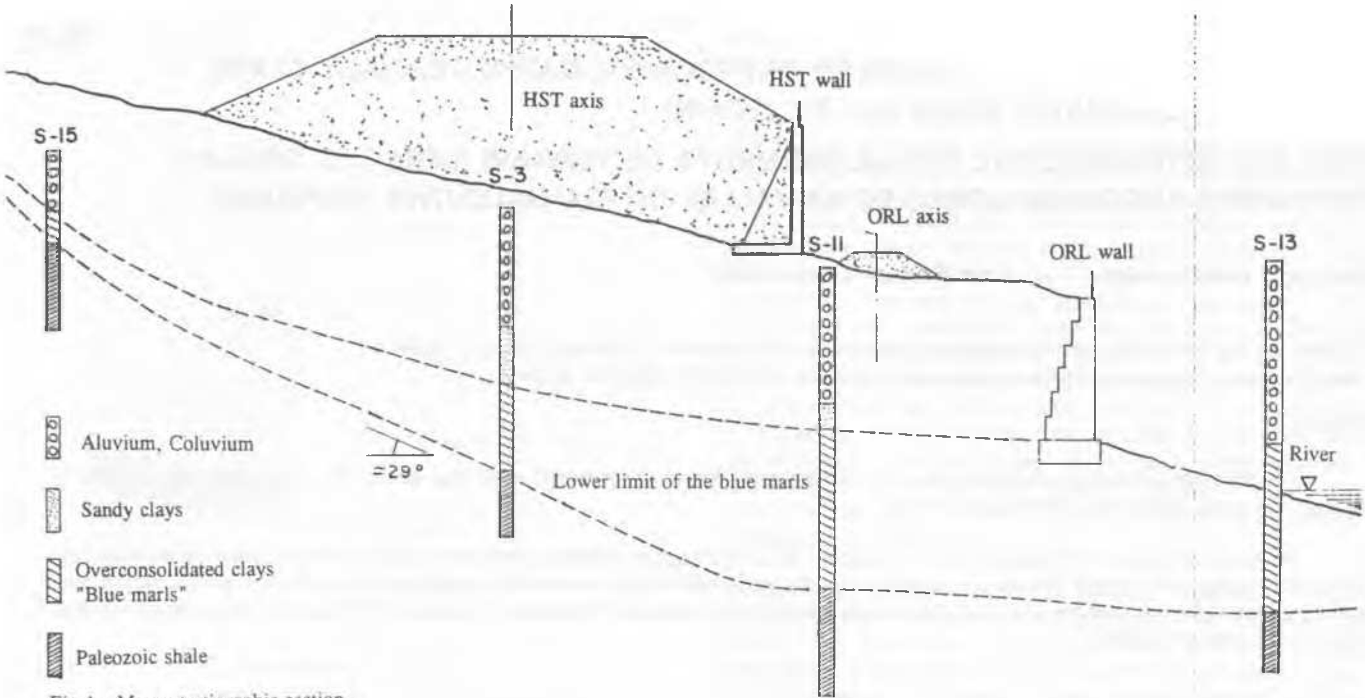

Fig. 1.- Mean stratigraphic section

and rocks of the slope in this zone. Cracks, fissures and settlements are observed, like most landslides. But the instability is not completely developed, because the shear strenght of the lower wedge is great enough to resist the shear stress imposed and transmitted by the upper wedge. Finally the landslide can occur if any of the following conditions are fullfilled :

a.- An increase of the pore water pressure, or an increase of the load supported by the upper wedge (like the man-made fills of theHST platform)

b.- A progressive decrease of the shear strenght along the slip surface under the upper wedge, which can attain in this zone the lower value of the residual strenght, if the strains and displacements of the shear zone are great enogh

c.- Simultaneous ocurrence of items a) and b)

During the movement of the mass, before the final equilibrium is attained, the upper wedge experiments great strains and deformations, because it must trespass the elbow which the slip surface presents usually between the upper and lower wedges (fig 4). By this reason the soils and rocks of the upper wedge experiment distorsions and cracking of very different patterns depending on the local circunstances of the rock.

The lower wedge, on the contrary, can follow a translational movement, along the bedding planes or along the contact with the substratum, which in many cases is the weakest zone of the rock media. In the present case both discontinuities are almost plane and horizontal. During the last phase of the landslide the distortion of the lower wedge can be very light. In this way, any installation or work placed on the suface can be displaced mounted on the wedge with a moderate or null damage, if the distance between the exterior and the slip surfaces is sufficiently great.

Both wedges are separated by one internal shear zone originated by

Fig 2.-General view of the landslide

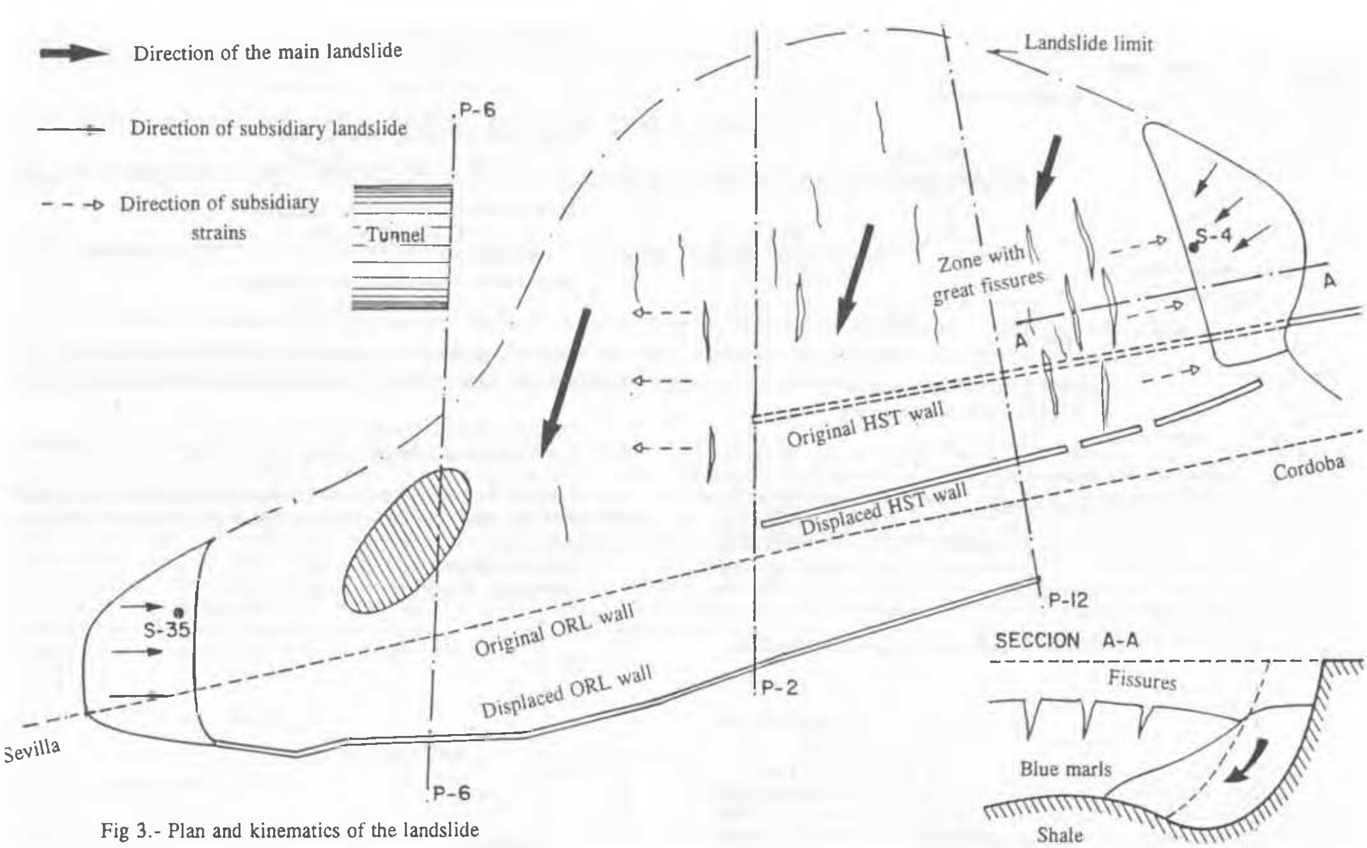

Fig 3.- Plan and kinematics of the landslide

the distorsión due to the elbow, and which develops near this discontinuity. This shear zone is progressively enlarged as the upper wedge pass through this elbow.

The landslide kinematics exposed points clearly towards the existance of a progressive failure in transversal direction. Firstly, the peak shear strenght along the slip surface under the upper wedge can be trespassed and the strenght decrease to the residual value during the first stage of the landslide, before the final collapse, if the shear strain and displacements are great enough, and this usually the case with the Guadalquivir blue marls. This residual strenght can be developed under drained condition. Under the lower wedge the peak shear strenght is attained only during the last movements of the slide and probably with undrained condition.

This landslide configuration took place in the case which is now exposed (fig.5).The transversal shear zone separating the two wedges was located between the tracks of the two railroad lines. The upper wedge was situated over the most dipping zone of the contact marl-shale. The lower wedge extended from this shear zone down to more or less the center of the Guadalquivir river course, comprising the area where is located the wall and the tracks of the ORL line. The contact marl-shale is in this zone almost horizontal.

The slip surface was not clearly detected with the borings, but it was almost sure that it was developed deep within the marls, or through the contact between the blue marls and the strata of paleozoic shales. Several arguments sustain this hypothesis:

a) If the slip surface were shallow, near the base of the ORL wall, the angular distortion and the inavoidable iregularities of the shear zone would be so great that the masonry of the wall would be completely destroyed. As it has been pointed out this retaining wall was displaced 12 m. towards the river with minor damages. This fact demostrates that the wall was located on the lower wedge, with an almost horizontal translational movement along a slip surface far away, several meters, of the foundation of the wall.

The HST wall, located almost over the transversal shear zone, between the two wedges, suffered some but not very important damages.

b) The river bank was also displaced in a similar amount. The trees situated between the ORL wall and the water remained vertical. It is evident that the root zone remained within the lower wedge and that the slip surface was deep.

c)The batimetry of the bottom of the Guadalquivir river, made after the slide, revealed an upheaval of 1-2 m. at the center of the course, at a distance of about 30 m.from the bank. This was probably the toe or the final part of the land slide. This fact points out also that the slip surface was several meters deep under the bottom of the river.

d) The numeric back analysis of the slide established that the worst slip surface, with the lowest safety factor, were situated in the contact or near the contact between marls and shales.

The sequence of the progressive failure and the two wedge landslide configuration is indicated in the fig.5.

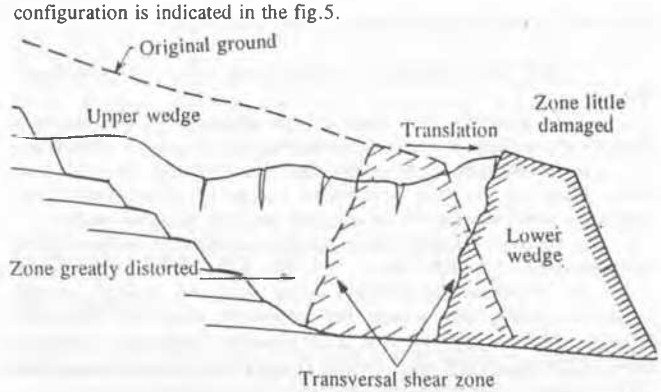

Fig 4.- Tipical morphology of a landslide in miocene Guadalquivir blue marls

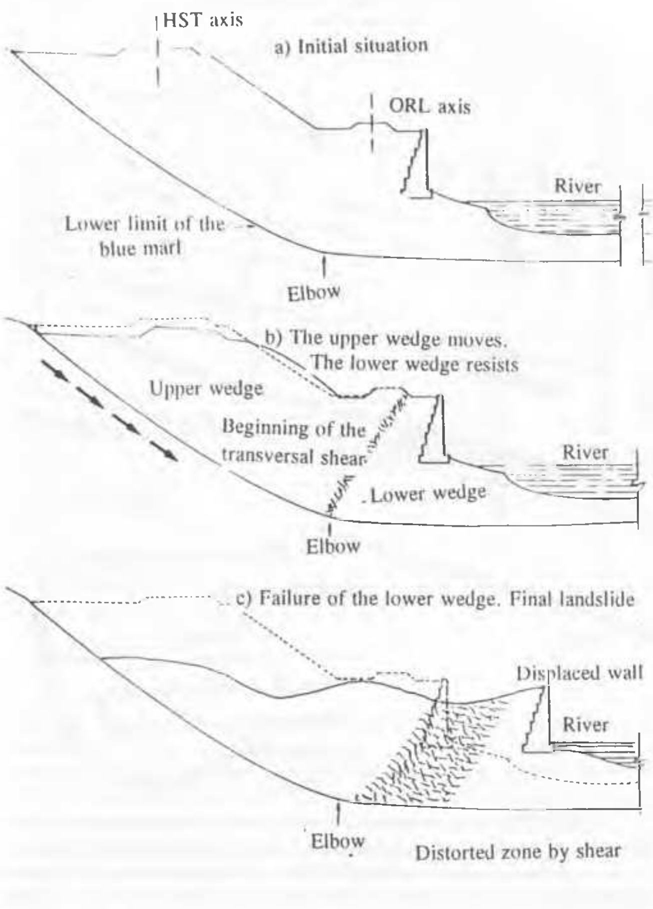

Fig.5 - Transversal cinematics of the landslide

A progressive failure took place also in plan or longitudinal direction. The landslide begun in the Sevilla side and propagated towards the Cordoba direction (fig.2). The extension and the tensile strains of the movilized mass of soils and rocks originated the opening of tranverse cracks. Several subsidiary small slides were observed at the ends of the main slope movement.

NUMERICAL BACK-ANALYSIS OF THE LANDSLIDE

Several items was aimed to be fullfilled with a numerical back-analysis:

a) To obtain the mean shear strenght parameters of the blue marls along the slip surface. It was based on the original topography of the slope.

b) To obtain the mean residual shear strenght parameters of the blue marls, based on the final equilibrium topography of the slope. This parameters were necessary for an adequate design of the repair works.

c) To know the safety factor against a landslide of the slope before the construction of the HST fills.

d) To obtain the probably actual peak and residual strenght parameters, taking into account the progressive failure in transversal direction which has been exposed in the preceding paragraphs. Under the upper wedge the strenght along the slip line was supposed to be the drained residual strenght, and under the lower wedge the undrained peak one.

It was employed the bidimensional Janbú method. The following parameters were obtained for the different hypotesis (fig.6):

Mean drained peak strenght :

If cohesion $c'=0$: Angle of friction $\varphi'=21.6\text{-}22.5°$

If $c'=1$ T/m^2 : $\varphi'=18\text{-}19°$

Mean peak undrained shear strenght :

$\varphi=0$; $c_u= 5.1\text{-}5.8$ T/m^2

Mean residual drained shear strenght :

$c'=0$; $\varphi'=12.9\text{-}15.4°$

Mean residual undrained shear strenght :

$\varphi'=0$; $c_u= 2.5\text{-}3.6$ T/m^2

For the hypotesis of a progressive failure, following the model of two wedges, the most probable strenght parameters for the blue marls were

Drained residual strenght : $c'=0$; $\varphi'=14.5°$

Undrained peak strenght : $\varphi=0$; $c_u = 8$ T/m^2

Finally, the safety factor of the slope without the fill of the HST line, that is the safety factor existing before the construction of the new railroad line, was :

Drained failure : $F=1.07\text{-}1.14$

Undrained failure $F_u = 1.4\text{-}1.43$

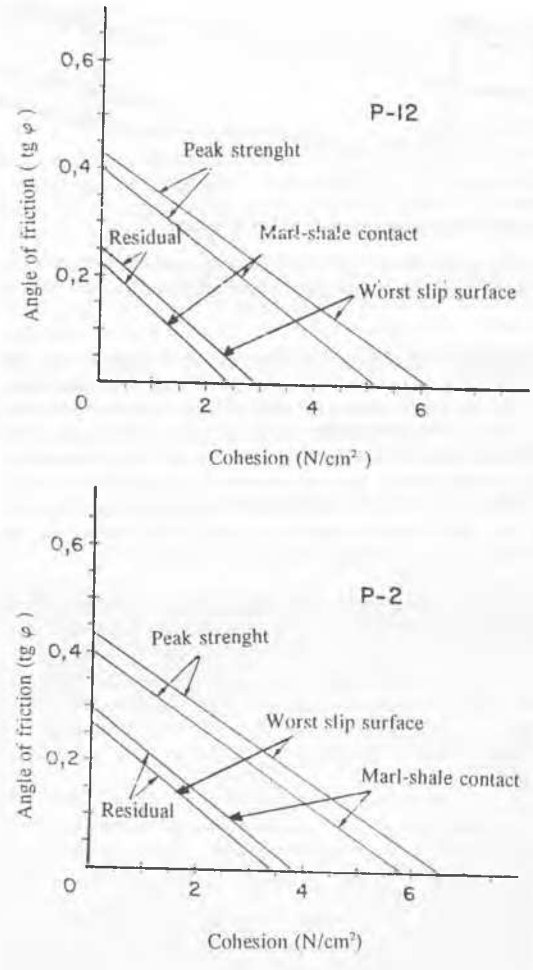

Fig 6.- Equilibrium shear strenght

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