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Neotectonic related geological risk at dams in the Mexico Basin: Guadalupe dam

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RESUMEN

Se analizaron los tres modelos tectónicos existentes del área de la Cuenca de México, con base en los cuales se elaboró un modelo tectónico que incorpora las estructuras geológicas comunes.

Posteriormente se identificaron diversas obras civiles a lo largo de estas estructuras que pudieran sufrir efectos negativos para su seguro funcionamiento, debido a la actividad neotectónica de dichas estructuras.

Como ejemplo del riesgo geológico para estas obras civiles que representan las estructuras definidas en los tres modelos, se analizó el caso de la Presa Guadalupe. Esta obra civil, de acuerdo con los registros de funcionamiento, ha tenido tres etapas de rehabilitación asociados con agrietamientos y asentamientos ocurridos en la cortina.

Esos asentamientos y fracturas están asociados con actividad geotectónica de fallas transtensionales cercanas.

Este estudio es un ejemplo de cómo la geotectónica de la región ha originado asentamientos y fracturas en edificios, inestabilidad y deslizamientos en caminos, así como zonas de alta permeabilidad en lagos y presas, causando graves daños y representa una contribución para futuros programas de prevención.

PALABRAS CLAVES: Presas, fallas transtensionales, neotectonismo, riesgo geológico, Sierra de Las Cruces, Cuenca de México.

ABSTRACT

Three available tectonic models for the Mexico Basin were analyzed. Based on these models a new tectonic model was developed. Engineering structures were identified that could suffer the effects of seismic activity.

Guadalupe Dam case is an example of risk from geological structures defined in the tectonic models. History records three stages of repairs of damage due to settlement and cracks that occurred in the dam wall.

These settlements and cracks are associated with neotectonic activity of a nearby normal or strike-slip fault.

Regional geotectonics is a cause of settlements and cracks, instability and landslides on roads, as well as high permeability zones beneath reservoirs, causing important damage.

KEY WORDS: Dams, normal faults, neotectonic, geological risk, Las Cruces Range, Mexico Basin.

INTRODUCTION

Scientific advance leads to periodical revisions of the influence of neotectonic activity on engineering structures. From a geological point of view, it is expected that the neotectonics associated with the Transmexican Volcanic Belt (TMVB), could affect such structures.

In order to know in detail the geological characteristics of the Mexico Basin, many studies were performed for decades, particularly because the nation's capital is involved.

Within the basin of Mexico a variety of natural processes have occurred, including tectonic, sedimentary, climatic and volcanic. The construction of roads, dams, tunnels, channels and wells modified the original characteristics of many sites, where major engineering structures are emplaced.

The reactivation of faults and fractures has affected structures in the lake zone and in the piedmont or transitional zone. As a result some of the dams for storage and flood control located in the Las Cruces Range have become important sources of hazard. Their safety becomes an important question because disasters due to failure of some major reservoir could seriously damage highly populated urban areas.

There are several dams in the northeastern Las Cruces Range, located along the edge of the southwestern Mexico

Basin, for irrigation, water supply and flood control. The original irrigation purpose of some of them is no longer essential because of the advance of urbanization.

In the meantime technological advances in exploration methods (both surface and subsurface) as well as in the construction and monitoring procedures of major engineering structures have been achieved, but these old dams and irrigation works may have serious safety problems that need to be attended too.

EARLIER GEOLOGICAL STUDIES

Geological studies of the Transmexican Volcanic Belt (TMVB) and the Mexico Basin, began at the conquest. The purpose of many of them was the location and extraction of mineral deposits, groundwater and drainage systems, and also for foundations of buildings.

Information about lithology, stratigraphy, hydrogeology, tectonics and soil mechanics is found in: Marsal and Mazari (1959), Mooser (1963,1975), Demant (1978), Marín-Córdova *et al*. (1986(a) and (b)), Aguayo and Marín-Córdova (1987), De Cserna *et al*. (1988), Huizar Álvarez (1996), Lugo-Hubp *et al*. (1997(a) and (b)), Díaz-Rodríguez *et al*. (1998), Campos Enríquez *et al*. (1996, 2003), García-Palomo *et al*. (2000, 2002), and many others.

Faulting in Huajúmbaro, Michoacán (Marín-Córdova *et al*.,1983), is an evidence of the presence of normal or strike-slip fault systems associated with lateral displacements in various regions of the TMVB. Other examples are anticlinal and synclinal structures in sedimentary rocks in Estado de Mexico, Hidalgo, Michoacán, Morelos, Puebla and Veracruz (Marín-Córdova *et al*., 1986 a, b).

The structural geology of the Mexico Basin has been studied by Mooser (1975), Marín Córdova *et al*. (1986 b) and De Cserna *et al*. (1988).

In these studies different geological structures are proposed for the Mexico Basin and specially for the Las Cruces Range.

According to Mooser's model, the Mexico Basin features four troughs: Cuautitlán, Peñones, Central and Oaxtepec. They are separated by grabens, orientated NE-SW.

Marín-Córdova *et al*. (op. cit.) defined sixteen NE-SW faults, separated between 4 and 6 kilometers, where pyroclastic and lacustrine deposits appear fractured, faulted and folded as well as fissured (Figure 1).

There are some common structures in the studies by Mooser and Marín-Córdova *et al*. For example the faults F-12 and F-13, are related to the Cuautitlán graben. Faults F-8 and F-9 are associated to the Peñones graben; while faults F-6 and F-7 to the Central graben and the F-4 and F-5 faults to the Oaxtepec graben.

There are also some common structures in the work of De Cserna *et al*. (1988). They make a reference to the Magdalena River fault and the Hondo river fault, corresponding to the Fosa Peñones graben of Mooser *et al*. and to the F-8 and F-9 faults of Marín-Córdova *et al*. In the first study, the structural cartography was based on five hundred observation points in the field and on 55 sections of the ridges that surround the basin in the west and east, as well as a reinterpretation of gravimetric information of the central parts of the basin. According to the nature of the displacement registered, these structures are considered lateral displacement faults.

Thus three structural models are similar in the main. They differ in coverage of the basin and in the objective of the study. These three studies are synthesized in Figure 2.

The Institute of Geology (Marín-Córdova *et al*., 1986), provided a geological cartography of the Mexico Basin at a scale 1:50,000, detecting zones with high permeability, artesianism and hydrotermalism in the structural lineaments (faults and fractures).

The analysis and correlation of all this information enables us to propose a geological and structural framework for the Mexico Basin and surrounding areas (Figure 1), where sixteen main faults are illustrated and which delimit fifteen blocks.

According to this model, the blocks are separated starting from axis oriented NW 35° SE, from the Miocene, generated by normal faults in that direction (Aguayo and Marín-Córdova op. cit.).

The fifteen blocks constitute horsts and grabens, which may be seen in the valleys of Tepexpan - Otumba and Tizayuca - Pachuca, delimited by the faults designated as 8 and 9 (Peñones graben), another by faults 12 and 13 (Cuautitlán graben). Mooser (op. cit.) and De Cserna *et al*. (op. cit.) attribute the Magdalena and Hondo rivers to faults.

The vertical components of the faults 12 and 13 were identified by Huizar-Álvarez (op. cit.), in the subsurface, from a stratigraphic correlation of water supply wells, at the Tizayuca - Pachuca valley (Cuautitlán Graben).

Fig. 1. Location of sixteen faults within the Mexico Basin after Marín-Córdova *et al*. (1986 b).

Recently García Palomo (2000 and 2002), in the TMVB and specifically in the Nevado de Toluca region of the Estado de Mexico and Apan, Hidalgo, mapped structures with regional dimensions and NE-SW orientations. He found a variety of structures with lateral displacements originated in the Middle Miocene and acting afterwards as normal faults.

The cracks in granular materials considered in this paper do not correspond to soil tension or contraction phenomena described by authors specialized in soil mechanics (Zeevaert, 1953, Juárez-Badillo, 1961). In the main areas where these cracks have been studied, with strikes NE 45° - 55° SW and NW 35° SE, within the Mexico Basin (Marín – Córdova *et al*., 2001), we have several engineering works as follows.

Considering the morphological features of the basin, the alignment of the main NE - SW transtentional faults and

CIVIL CONSTRUCTIONS AFFECTED	NEOTECTONIC STRUCTURES NE-SW and NW-SE
1. Zone of the El Caracol solar evaporator, estado de México	F-9 and Distensive Axis
2. Field of exploitation of brine wells Sosa Texcoco, estado de México	F-8 and F-9 and Distensive Axis
3. Zacatenco Professional Unit (IPN), Distrito Federal	F-10
4. Crossing of Azcapotzalco Avenue and Cien Metros avenue, Distrito Federal	F-10
5. Indios Verdes (Insurgentes Avenue), Distrito Federal	F-10
6. National Avenue and the Highway Mexico-Pachuca, estado de México	F-11
7. Lechería - Texcoco road branch, estado de México	F-7 and F-8
8. Emiliano Zapata Avenue at San Pedro Xalostoc, estado de México	F-9
9. Acayuca, Hidalgo	F-14
10. Calzada Ignacio Zaragoza and Peñón del Marqués, Distrito Federal	F-6
11. Añil Avenue at Sports Palace, Distrito Federal	F-8
12. Central Avenue at Nezahualcóyotl and Ecatepec, estado de México	F-7 and F-8
13. San Juan de Aragón Lake, Distrito Federal	F-8
14. Talismán Avenue, Distrito Federal	F-9
15. Iztapalapa Avenue, Distrito Federal	F-7 and F-8
16. Benito Juárez International Airport Zone	F-8
17. Mexico - Cuernavaca road, Distrito Federal	F-6 and F-7
18. Zócalo and Alameda (downtown), Distrito Federal	F-9
19. Echegaray and La Florida, estado de México	F-10
20. Nabor Carrillo Lake, estado de México	F-8
21. Villa Coapa, Distrito Federal	F-8
22. Viaducto at the corner of Cuauhtémoc Avenue, Distrito Federal	F-9
23. Xico, estado de México	F-5
24. Ixtapaluca, estado de México	F-4 and F-5
25. Ayotla, estado de México	F-5
26. Chalco, estado de México	F-4

the location of the cracked described areas, a NW 35° SE axis joins the Popocatépetl volcano and the Tequisquiac-Huehuetoca zone, as well as the lowest portion of the Mexico Basin, corresponding to the former Texcoco Lake and the thermal Peñón de los Baños zone, where the NE - SW blocks start to separate from each other. Another distensive axis interpreted within the basin, oriented NW 35° SE, is aligned with the valleys of Ixmiquilpan (Hidalgo), the Apizaco region (Tlaxcala) and La Malinche volcano.

Dams in the earstern slope of the Las Cruces Range, could show the effects of some of these normal or strike-slip faults.

GUADALUPE DAM

Guadalupe Dam is located in the northeast slope of Las Cruces Range, where several other dams have been constructed. Their primary objectives were irrigation, control and water supply.

Guadalupe Dam is built on the Cuautitlán river, where the F-12 lineament (Cuautitlán graben), is one of the more active faults. The history of its construction (1936-1943) and the three restoration steps and operation until 1976 are taken into account (Alberro *et al*., 1976).

Figure 3 presents the simplified geology of the area. The volcanic units and alluvial and lacustrine outcrops are Tertiary and Quaternary.

The dam foundation rests on heterogeneous deltaic alluvial deposits, in a valley probably drained by an ancient river bed. Because of this setting differential settlements caused effective tensional stresses in the structure. Several SSW - NNE and WNW - ESE, fractures affecting the Tertiary units have been documented (Alberro *et al*., op.cit.).

HISTORICAL PERFORMANCE OF THE GUADALUPE DAM

Initially, this was a rock fill dam with a concrete face at its upstream slope, with a length of 450 m and a height of 29 m above the terrain.

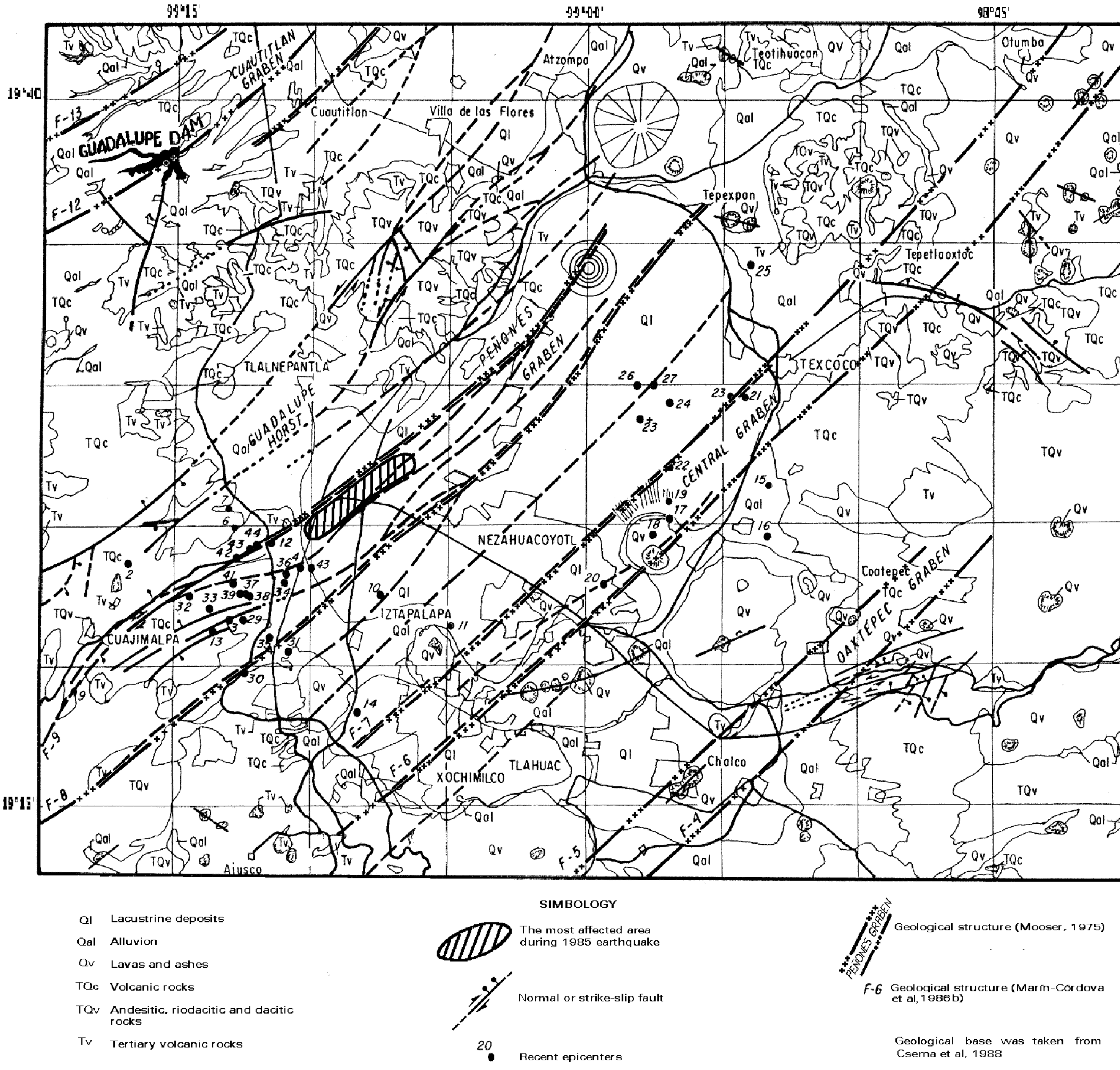

Fig. 2. Schematic map with structural intergrated models after De Cserna *et al*. (1988).

In 1947, because of excessive water leaks (4 m^3/s), it was emptied. Its section was modified, and it became a rock and clay dam with a sloping core of clay. On September 1952, when the reservoir was almost full, a new water leak occurred (0.5 m^3/s). After emptying the reservoir cracks were observed in the upstream face. Since then the reservoir was kept at very low levels, until 1968 when it was repaired again; up to 1967 its behavior was satisfactory (Alberro *et al.*, op. cit.).

In 1967 the dam was again repaired, and special instruments were installed at the clay trench linking the core with the foundation. Inclinometers were placed to study the effect of the hydraulic load of the reservoir, both up- and downstream.

Measurement devices were installed mainly at the stations 0+120 and 0+260. This instrumentation included pressure cells, piezometers and longitudinal extensometers, as well as surface bench marks and inclinometers. They were installed both up and down stream. The purpose was to observe the behavior of the dam (Figure 4).

Soil mechanics studies to explain the behavior of

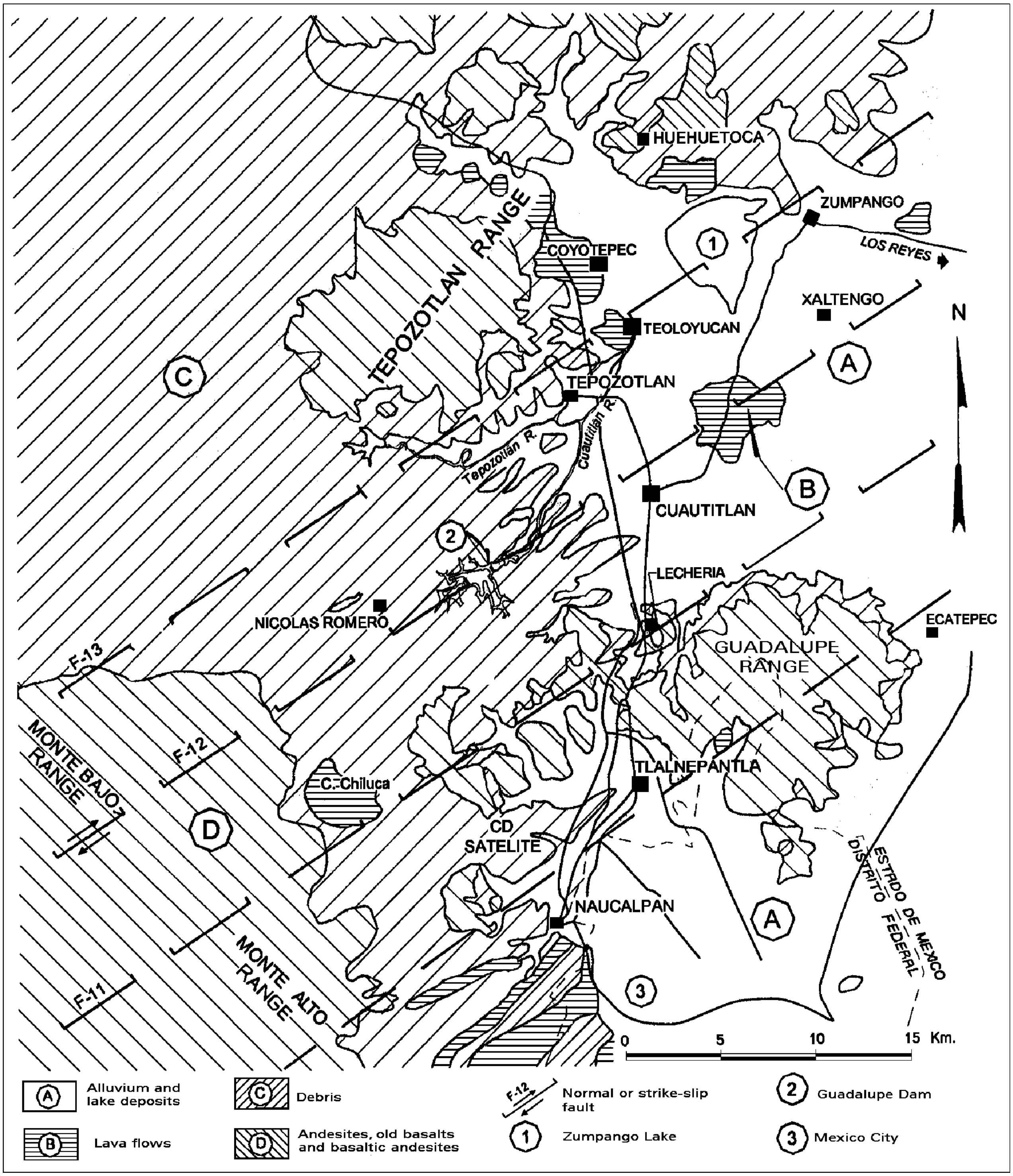

Fig. 3. Geological map.

Guadalupe dam have been extensive and detailed, using the data provided by of the installed pressure cells, extensometers, benchmarks and inclinometers.

Alberro *et al.* (op.cit.), concluded that, after the construction, the core and the downstream back of the dam, at the station 0 + 150 underwent settlement and were displaced towards a zone of the foundation that coincides with the zone of thicker sediment carried. The embankment and the trench upstream from the cut-off were displaced upstream.

Alberro *et al.* (op. cit.) reported that the NNE - SSW axis of maximum thickness seems to be oblique to the axis of the dam and parallel to the tectonic fractures within the

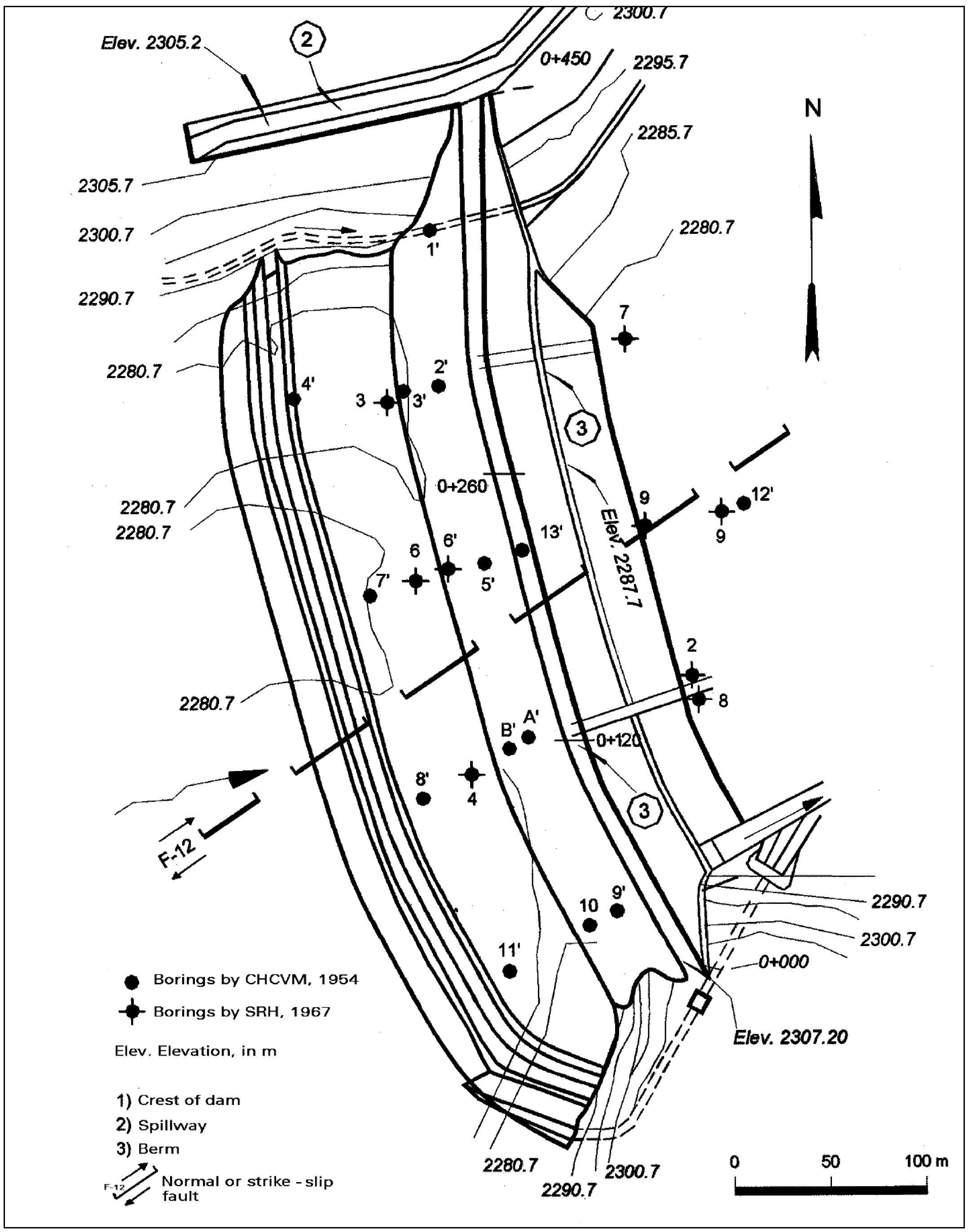

Fig. 4. Boring location and transtentional fault at Guadalupe dam, after Marín Córdova *et al.* (1986 b).

area. It might constitute an ancient river bed before the sedimentation of alluvium and the deltaic generation originated at this basin during the Early Quaternary.

DISCUSSION

As shown in Figure 1, the main normal or strike-slip faults crossing the southwestern portion of Mexico Basin are located between the F-7 and the F-14 faults. Many of them coincide with river beds that drain the zone. These features are summarized here:

Table 1

RIVER NAME	DAM	TRANSTENTIONAL FAULT
Tepotzotlán	La Concepción	F - 13
Cuautitlán	Guadalupe	F - 12
Tlalnepantla	Madín	F - 11

Guadalupe Dam was considered here for geologic risk, because there are extensive operation reports, where settlements and cracks are described. It was built on Cuautitlán river that, according to the geological – structural studies, is located on one of the main fault alignments (F-12). It had not been considered because it was unknown at construction time (Figure 2).

From the analysis of available information in the early stage (1936), several cracks were associated with 2.10 m settlements, for a dam 28.50 m high, founded on silts and sands 7 to 21 meters thick, underlain by tuffs.

After repair (1948), there were a longitudinal cracks, reported in 1952, and a 2 x 3 x 5 m cavity. Later, revision undertaken at the 0 + 120 and 0 + 260 stations reported cracks transversal to the dam axis.

Based on the behavior of Guadalupe Dam and its relation to the geological-structural frame of the Mexico Basin, we note the effects originated by its emplacement on granular materials, with a coincidence between the direction of the cracks of the dam and that of the F – 12 strike-slip fault.

This geological anomaly may correspond to the trace of the F-12 fault, as shown in Figure 3 which, according to the definition of Slemmons and McKinney, (1977), may be considered an active fault.

CONCLUSIONS

After several decades, the dams constructed at the northeastern slope of the Las Cruces Range no longer fulfill their objective. At present they are surrounded by residential zones, and they represent a risk in the event of geological phenomena.

This risk is more likely in the case of dams that were emplaced on the traces of faults that might be reactivated because of tectonic events, as found in the Volcanic Transmexican Belt.

This could also occur at other dams in the area: La Concepción and Madín among others, constructed on fault alignments caused by regional geological tectonic events.

It is convenient to implement programs for monitoring dam evolution. Prevention must be supported by local and detailed geological investigations, and by instrumental information.

BIBLIOGRAPHY

AGUAYO CAMARGO, J. E. and S. MARÍN-CÓRDOVA, 1987. Origen y evolución de los rasgos morfotectónicos post-Cretácicos de México. Boletín de la Soc. Geol. Méx. Tomo XLVIII, N° 2, p. 15-39.

ALBERRO, A. J., T. J. L. LEÓN, J. J. HANEL, P. M. VERA and N. J. FLORES, 1976. "Guadalupe", Comportamiento de presas construidas en México, S. R. H., C. F. E., Instituto de Ingeniería, UNAM. P.3-39.

CAMPOS-ENRÍQUEZ, J.O., O. DELGADO RODRÍGUEZ, R. CHÁVEZ SEGURA, P. T. GÓMEZ CABRERA and E. L. FLORES MÁRQUEZ, 1996. The sub-surficial structure of Chalco sub-basin (Mexico City) inferred from a geophysical cooperative study. *Geophysics, 62,* 23-29.

CAMPOS-ENRÍQUEZ, J. O., D. ALATRISTE-VILCHIS, R. HUIZAR-ÁLVAREZ, R. MARINES-CAMPOS and M. A. ALATORRE-ZAMORA, 2003. Sub-surface structure of the Tecocomulco sub-basin (northeastern México Basin) inferred from geophysical studies and relationship to the regional tectonics. *Geofís. Int.,* 3-24.

DE CSERNA, Z., M. DE LA FUENTE-DUCH, M. PALACIOS NIETO, L. TRIAY, L. M. MITRES SALAZAR and R. MOTA PALOMINO, 1988, Estructura geológica, gravimetría, sismicidad y relaciones neotectónicas regionales de la Cuenca de México, Boletín 104. México, Instituto de Geología. UNAM, 71 p.

DEMANT, A., 1978, Características del Eje Neovolcánico Transmexicano y sus problemas de interpretación, *Revista del Inst. de Geol., UNAM. 2,* 172-187.

DÍAZ - RODRÍGUEZ, J. A., R. LOZANO SANTACRUZ, V. M. DÁVILA-ALCOCER, E. VALLEJO and P. GIRÓN, 1998. Physical, chemical, and mineralogical properties of Mexico City sediments: a geotechnical perspective. *Can. Geotech, J., 35,* 600-610.

GARCÍA PALOMO, A., J. L. MACÍAS and V. H. GARDUÑO, 2000. Miocene to recent structural evolution of the Nevado de Toluca volcano region central, México. *Tectonophys., 318,* 281-302.

GARCÍA PALOMO, A., J. L. MACÍAS, G. TOLSON, G. VALDEZ and J. C. MORA, 2002. Volcanic stratigraphy and geological evolution of the Apan region, east-central sector of the Trans Mexican Volcanic Belt. *Geofís. Int., 41, 2,* 133-150.

HUIZAR ÁLVAREZ, R., 1996. Hydrochemistry of the aquifers in the Río Las Avenidas basin, Pachuca, Hidalgo, Mexico. *Water, air and soil pollution, 96*, 185 – 201.

JUÁREZ BADILLO, E., 1961, Mecanismo de las grietas de tensión en el Valle de México, Tesis Doctoral de Ingeniería, DEPFI, UNAM, 64 p.

LUGO HUPB, J. *et al*., 1997(a). Causas principales de deslizamientos de tierra en el estado de Hidalgo, Resúmenes, II Convención sobre la evolución geológica de México y recursos asociados, Instituto de Investigaciones en Ciencias de la Tierra e Instituto de Geología, UNAM, p. 33 - 34.

LUGO HUBP, J. *et al*., 1997(b). Geomorfología preliminar de la sierra de Los Pitos, Hidalgo, Resúmenes II Convención sobre la evolución geológica de México y recursos asociados. Instituto de Investigaciones en Ciencias de la Tierra e Instituto de Geología, UNAM, p. 94.

MARÍN CÓRDOVA, S., C. J. E. AGUAYO, V. J. MANDUJANO and V. I. GASCÓN, 1983. Geología con fines económicos en los municipios de Jungapeo, Cd. Hidalgo, Zinapécuaro y Zitacuaro, en el estado de Michoacán, Convenio Inst. Geol. UNAM y Gobierno del Estado de Michoacán, Inédito, 40 p.

MARÍN CÓRDOVA, S., C. J. E. AGUAYO, A. R. HUIZAR and V. J. MANDUJANO, 1986(a). Geología en el Valle de México con fines geohidrológicos, Convenio Inst. Geol. UNAM y CAVM N°. 85-405, Inédito, 90 p.

MARÍN CÓRDOVA, S., C. J. E. AGUAYO and V. J. MANDUJANO, 1986(b). Sistemas mayores de fallamiento en la Cuenca de México y su relación con la sismicidad. Resúmenes de la VIII Convención Geológica Nacional; México, DF. p. 209-211.

MARÍN CÓRDOVA, S., J. A. DÍAZ RODRÍGUEZ, E. JUÁREZ BADILLO, G. M. CHÁVEZ, M. F. VALDEZ and B. H. HERNÁNDEZ, 2001. Nuevo Aeropuerto Internacional de la Ciudad de México, Diagnóstico Geotécnico Ambiental, División de Estudios de Posgrado de la Facultad de Ingeniería, PUMA, UNAM, Informe Inédito, 34 p.

MARSAL, R. J. and M. MAZARI, 1959. El subsuelo de la Ciudad de México: México D. F., Facultad de Ingeniería, UNAM, 377 p.

MOOSER, F., 1963. Historia tectónica de la Cuenca de México. Bol. Asoc. Mexicana. *Geol. Petrol. l5,* 239-246.

MOOSER, F., 1975. Historia geológica de la Cuenca de México, Memorias de las obras del Sistema de Drenaje Profundo del Distrito Federal, D.D.F. México, Tomo I, 7-38.

SLEMMONS, D. B. and R. MAC KINNEY, 1977. Definition of active fault, U. S. Army Corps of Engineers, Waterway Experiment Station, Misc, paper S-77-8, 22p.

ZEEVAERT, L., 1953. Outline on the stratigraphical and mechanical characteristics of the unconsolidated sedimentary deposits in the basin of valley of Mexico, 4º. Congr. INQUA. Roma Pisa, Actas, 2, 3-12.

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