Historical and Modern Earthquake-Resistant Construction in Turkey

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Strong earthquakes occur frequently in Turkey and nearly 40% of the country is subject to dangerous earthquakes. Records of 2000 years attest the continuous destructive force of these quakes. The Turkish people - the architects in the great cities having at their disposition all the technical and financial resources of the Government, as well as the population of little provincial towns and rural districts limited to the local sources and materials - have more than 700 years experience in fighting earthquake damages. I think that the experience of our people during so long a time under difficult conditions should be of general interest. Perhaps our experiences and observations could be useful to countries having similar geographic, climatic and economic conditions.

For this reason, I want to explain at first the seismological and geological situation of our country and then to show briefly the measures against earthquake damage used by our people in past and modern times.

Geological and seismological structures of Turkey

Anatolia and Trakya - the Asiatic and European parts of Turkey - are an entirely alpine country belonging to the alpine orogenic system of Eurasia; the country consists of two mountain ranges surrounding a number of interior tablelands: The northern and southern Anatolian ranges belong to the two main branches of the eurasian orogenic zone; 1 - The "alpide branch" (Northern Alps - Carpathian Ranges - Northern Balkan Mountains - Northern Anatolian Ranges - Northern Itanian Folds) in the north and 2 - The "dinaride branch" (Southern Alps - Folds of Yugoslavia, Albania, southern and central Greece - Southern Anatolia Ranges - Iraq - Southern Iranian Folds) in the south. In Eastern Anatolia, these two ranges are separated by a tectonic line (tectonic scar); in Central and Western Anatolia, the space between these ranges is occupied by intermediate masses. In the Aegean region, the SW - NE extending Aegean Folds are intersected between these two main branches. All these folds show typical orogenic rocks and sediments as: Mesozoic green rocks and radiolarites, a thick succession of "alpine" Mesozoic limestones and Mesozie dynamometamorphosed rocks. Intensive folding and overthrusts of "alpine" dimensions are frequent here.

The southern foreland of the orogenic zone, the Arabian Plateau, penetrates into Southeast Anatolia; the northern foreland (also the Caucasian branch of the alpine system) does not enter into Turkish territory.

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DEVELOPMENT OF ASEISMIC CONSTRUCTION

The alpine folding phase began in the Cretaceous period and ended after the Middle Eocene in the interior part and after the Middle Miocene in the exterior part of the Anatolian folds.

While the orogenic development of Anatolia and Trakya is nearly the same as in Europe, the epirogenic phase succeeding the orogenic movement is quite different. In comparison with Europe, the vertical epirogenic movements are more intensive in the Turkish territory. Numerous dislocations cover Anatolia and Trakya; fault systems and grabens (filled with Oligocene, Neogene and Quaternary deposits) running parallel or perpendicular to the neighbouring alpine folds intersect folds and intermediate masses. Young volcanic phenomena accompany numerous of these fault lines.

These movements began early in the Miocene (or even in the Oligocene), became frequent in the Upper Neogene and ended late in the Quaternary, in very recent times. Vertical displacements of more than 1000 meters have been observed in the Neogene deposits; disturbed Pliocene and Pleistocene beds are abundant.

During this phase the Marmara and Aegean basins broke down (Lower Quaternary) so that the physiography of large parts of Anatolia expresses the main epirogenic deformation only slightly reduced by erosion.

No relationship can be established between seismic activity and orogenic structures because important shocks are recorded not only from alpine folded zones, but also from unfolded intermediate masses; though the seismic events are strongly associated with young epirogenic faults .

We can distinguish in Turkey four first category earthquake zones in which disastrous shocks occur, and have occurred continually since Antiquity; severe damage is reported in all towns situated within the Zones. These first-category zones are:

1. The Aegean - Marmara Zone in Western Anatolia and in Trakya, a veritable network of faults and grabens resulting from the breaking down of the Aegean and Marmara basins and extending from the Aegean coast eastward and south-eastward far into the country.

2. The Northern Anatolian Zone - not a single earthquake rift, but a more or less large ribbon of tectonic depressions, grabens and faults situated in the northern Anatolian folds and roughly parallel to their axes. The total length of this zone, extending from the Marmara basin in the west as far as the Aras Valley in the east, is about 1500 km. Its most active part (during the last years' seismic activity) has a length of more than 800 km.

3. The Central Anatolian Zone - including numerous earthquake centers situated on faults cutting the intermediate masses and on the dislocations forming the boundery between these masses and the alpine folds.

4. The Southeastern Anatolian Zone is the northeastern extension of the great "Syrian Graben", the rift valley system running in south-north direction from the Eastern African Lakes Region northward to the Maras

region in Turkish territory. Here, this fault system enters the Southern Anatolian Folds, turns eastward and follows the axes of these folds to the Turkish - Iranian frontier.

In the secondary zones shocks are also frequent but serious damage rarely occurs; these zones are scattered over the area between the first class zones.

So, we have in Turkey some seismic zones of which the geographical dimensions can be compared with the Californian San Andreas rift.

Among the earthquakes recorded in Turkey during the past 50 years, two have had the magnitude 8; these shocks (Murefte in the Marmara region, 1912 and Erzincan in Northeastern Anatolia, 1939) are among the 20 strongest quakes in the world since 1904. Five of the quakes which occurred in Turkey since 1918 have had the magnitude 7,0 - 7,75: Ladik - Erbaa in N.E. Anatolia, Dec. 20, 1942; Erbaa - Tosya, Nov. 28, 1943; Gerede in N. Anatolia, Feb. 1, 1944; Karaburun in the Aegean region, July 23, 1949 and Yenice - Gonen in N.W. Anatolia, March 18, 1953. Nine shocks reported in the same space of time have had the magnitude 6,0 - 6,9; Almus in N. Anatolia, April 29, 1923; Pasinler - Erzurum in N.E. Anatolia, Sept. 13, 1924; Dinar in S.W. Anatolia, Aug. 7, 1925; Torbali in W. Anatolia, March 21, 1928; Susehri - Sebinkarahisar in N.E. Anatolia, May 18, 1929; Isparata in S.W. Anatolia, Sept. 11, 1930; Marmara Sea, Jan. 4, 1935; Mugla in S.W. Anatolia, May 23, 1941 and Bingol in S.E. Anatolia, Aug. 17, 1949 (Magnitudes calculated by Professor J. P. Rothe, Strasbourg, in an unpublished report).

Within the area of the destroyed regions, numerous of the quakes reported from past times must have had a magnitude of more than 7,5 and an intensity of X degrees and even more. The average periodicity of these catastrophes is 60 - 80 years.

For the four first category earthquake regions of Turkey, we can establish the following number of reported shocks:

Aegean - Marmara region: 350 shocks since the 11th century.

Northern Anatolia: 191 shocks since the 2nd century.

Central Anatolia: 42 earthquakes since the year 1205.

Southeastern Anatolia: 135 shocks since the year 110.

Besides these shocks, disastrous in their majority, nearly all parts of Anatolia are shaken continously and several hundred non-destructive light quakes are recorded every year; for example, 100 - 150 of such shocks are felt every year in the Aegean region.

The facts mentioned above show that, unfortunately, Turkey is one of the most seismic regions of the world. Important parts of the country are continuously exposed to earthquake destruction and heavy shocks occur frequently in the richest and most densely populated regions.

DEVELOPMENT OF ASEISMIC CONSTRUCTION

Since 1938, more than 50,000 persons have been killed and more than 100,000 buildings destroyed by earthquakes.

It is a surprising fact that no effective attempt had been made in the antiquity for the protection of the big Anatolian cities against seismic dangers. The disastrous effects of seismic shocks on the history of antique cities is proved by numerous documents; more than one of these towns had been demolished and deserted only a short time after its establishment: Pamukkale - Hierapolis in S.W. Anatolia was deserted after two disastrous shocks in the second century; Antakya - Antiochia in S.E. Anatolia has never regained its formerly splendour and importance lost during the earthquake of 527/28; the town of Anavaraza, the former capital of the Adana region in S. Anatolia, disappeared at the same time. Even today, we can see the effects of earthquake destruction in the ruins of the antique cities of Western Anatolia, as: Bergama - Pergamon, Efes - Ephesos, Balat - Miletos, Yenihisar - Didymia, Geyre-Aphrodiseas, Pamukkale - Hierapolis.

It is a well known historical fact, that the principles of town planning and town building had been developed during the Sumerian and Babylonian period in the lower Euphrate and Tigris region, where seismic problems are practically nonexistant. The antique cities of the old Greek and Roman periods had been built following this Mesopotamian model. This perhaps explains the fact that the seismic danger was completely neglected by the people who built the antique cities in Anatolia.

On the other hand, the Turkish people since their arrival in the actual Turkish territories (13th century), tried to protect the buildings in towns and villages against the continuous earthquake danger.

Historical and modern earthquake-resistant constructions:

I do not intend to discuss here all the protective measures invented for the construction of the big architectural monuments (for instance mosques) of the 15th, 16th, 17th, and 19th centuries in Istanbul, Edirne and Bursa. I cite here only one typical fact: While the churches of the formerly Byzantine period had been covered by simple cupolas (domes), the classic Turkish architecture used as cover of the big mosques, systems of cupolas consisting of a wide central dome supported by ranges of semi-cupolas. These cupola systems resist shocks better than single cupolas. The cupola of the former church of Aya Sofya (the largest remaining example of Byzantine architecture in Turkey) was thrown to the ground 20 years after its construction by the earthquake of 557 and was severely damaged in 1305 and 1344. It was later strengthened by thick buttresses against the effects of the earthquakes. But the big mosques of Istanbul, Edirne and Bursa covered by the systems of cupolas mentioned above have remained essentially undamaged until today even though situated in first class earthquake regions where strong shocks continually occur.

Where foundation on solid rock ground was not possible, heavy buildings were placed by the Turkish architects on inverted vaults and cupolas. The big mosque of Sultan Suleyman erected in 1566 on the upper edge of a sharp escarpment dominating the Golden Horn in Istanbul was protected against landslips by a system of pillars more than 50 meters high supporting the building and descending to the solid rock at the foot of the escarpment.

When we study the methods used by the population for the protection of buildings in towns and villages, we must distinguish several regions each characterized by distinct local building materials and climatic conditions. So, we have the following different zones:

1. In the regions where timbers were easily available, as in the forest covered mountain zones of Northern Anatolia or in the ports of the Marmara basin, the Byzantine stone or brick buildings were succeeded in Turkish time by wooden construction of one, two and even three floors. Simple houses, public buildings and palaces were all constructed in this manner. Because of their excellent resistance against seismic shocks, these wooden buildings, typical of the old quarters of Istanbul and other towns of the Marmara region, were built until very recent times even though more fire-proofed building material was available. In consequence of the wide spread use of this building type, damage and loss of life were relatively light in Istanbul during the heavy shocks of 1509, 1718, 1763, 1766-67 and 1894 and in the Marmara Sea region in 1912 and 1935.

In the villages situated in the mountainous part of the Northern Anatolia seismic zone, wooden buildings of one or two floors are prevailing too and the aspect of the rural agglomerations of this country resembles very much the villages in the Swiss and Austrian Alps.

2. Another earthquake-resistant house type has been developed in some parts of Northern Anatolia (Black Sea region) and in the Aegean seismic zone. Here the high degree of atmospheric moisture excludes the use of much timbers. In some parts of the Black Sea region, the lower floor of the house is generally built of stone or brick on a stone foundation and only the upper floor of wooden construction. This part of the building is most exposed to seismic oscillations. In the Aegean region, wooden frame-work in the walls assures the earthquake-resistance of the structure and supports the weight of the roof. The spaces between the frames are filled with stones, bricks or adobe. In the warmer parts of this region, walls are formed by sheets of lattice nailed upon the interior and exterior sides of the framework and covered by plaster. Even if the filling material between the frames breaks down during a shock, the framework resists and the building cannot collapse.

3. Quite different conditions prevail in the seismic zones of Central and Eastern Anatolia. These regions are without forests and are far from the sea; timbers are expensive and can be used only for reinforcement of other material. Hot summers with more than 30° Centigrade in the shade alternate here with cold winters (as much as 30 below zero in Central and 35 in Eastern Anatolia; temperature changes abruptly between daily sunshine and nightly frost. Construction material is exposed to extreme temperature variations; cold winters need thick walls.

In the high and cold regions of Northeastern Anatolia subjected to extreme climatical conditions, old town houses are two floor buildings with very thick stone walls; these walls are reinforced by horizontal continuous timber frame inserted between the stone layers of the wall with a vertical spacing of 70 - 80 cm. The efficiency of these frames in assuring the stability of the building against shocks has been proved in Erzurum during the big earthquakes of 1859 and 1901.

In the dry parts of Central and Eastern Anatolia, the one or two floor adobe construction is the prevailing old house type in towns and villages. Here too, horizontal continuous wooden frames inserted in the adobe wall with a vertical spacing of 70 - 100 cm., and well connected to each other at the corners of the building, assure the stability of the structure. This house type has been tested frequently in the Afyonkarahisar, Corum, Erzincan, Malatya and Van regions by numerous historical and recent earthquakes. This building system is used also in the other parts of the country.

During the strong earthquake of March 18, 1953 in Northwestern Anatolia (magnitude: 7,75), one of the few surviving buildings in the nearly completely destroyed little town of Yenice (near the epicenter of the shock) was a frame reinforced adobe structure nearly 100 years old. The building was situated immediately on the earthquake fault showing here a horizontal displacement of 4 meters and a vertical displacement of 1 meter. This fact proves better than a long discussion the value of the frame-reinforcement of adobe walls.

In the cold regions of Central and Eastern Anatolia, the cover of buildings is a special problem from the point of view of seismic construction. The local type of thin tiles generally used in the villages, does not resist against strong frost and they are destroyed rapidly. Most of the roofs are flat and covered with a thick layer of clay or soil and therefore are very heavy, an important deterant to the seismic resistance of the structure. To eliminate this danger, the horizontal timbers supporting the roof-cover project at every side of the house nearly 50 cm. or even more. So the weight of the roof is distributed over the full breadth of the wall and the roof timbers cannot break down when the walls oscillate during the shocks.

4. A special roof support has been developed in the cold mountain regions of Denizli and Burdur in Southwestern Anatolia. Here the two floor village houses are built of stone without any frame work, but the clay covered heavy roof is supported by thick wooden buttresses, so that the weight of the roof does not bear on the walls. This system of removing the roof weight from the walls eliminates one of the main causes of collapse. This buttress system prevented the collapse of many buildings in the rural sector of Burdur during the strong earthquake of 1914.

5. Other principles have been used in the warm regions of Adana and Hatay (Mediterranean sector of Anatolia). Here, the old earthquake-resistant village house consists of a light wooden frame supporting the roof. The walls are formed by a dense network of reed and tall branches (similar to those used for fences) and covered with a plaster of clay or lime. This house type has been abandoned in recent times during the economic development of the region and therefore, considerable damage occurred during the shocks of 1945 and 1952.

This discussion shows that the Turkish people in towns and villages have 700 years of experience in the protection of all kinds of buildings against earthquake damage. The efficiency of construction types developed by them have been proved during numerous shocks.

This experience shows, that - within certain limits - buildings can be preserved from earthquake damage with measures easily to be applied by the people using only local building material. This is important for inaccessible localities, as mountain villages, where modern building materials are unobtainable. At the other hand, we must recognize that, in spite of the excellent antiseismic qualities of these strucutures, some of them are quite primitive. In fact, during the last 5 years village people have demanded modern houses built with bricks and concrete. The present production of modern construction materials, as cement and iron, cannot satisfy these demands. So the amelioration of housing conditions in the rural parts of the seismic regions has become an important social and technical problem requiring the help of the Government.

While the old local construction types still prevail in the villages, construction work in the towns uses modern materials and all the modern building techniques. Modern town buildings show no local particularities.

Construction work in the rural and town districts of the seismic regions is actually scheduled following the "Regulations for construction in seismic zones" established by the Ministry of Public Works which is charged by a special law (No. 4623, 1944) with the control of building and town planning work in the earthquake regions of Turkey.

These regulations profit largely by the above mentioned experiences. For instance, reinforced concrete frames must be inserted in brick and stone walls below the roof; adobe constructions must be reinforced by at last three continuous wooden frames (above the foundation, below and above the windows).

The regulations permit stone and brick buildings to have a maximum of three floors and wooden houses a maximum of two. Adobe structures of more than one floor are not allowed. An underground floor can be added in all cases.

For the static calculations, the effect of the horizontal component of seismic shocks is 0.02 - 0.04 for first class and 0.01 - 0.03 for second class earthquake zones (varying with the underground conditions). Though the degree of seismic shocks occurring in Turkey is higher than in the other countries of the Mediterranean basin, the horizontal component used in Turkey is considerably lower than the component applied in these countries (Italy: 0.05 - 0.10; Greece: 0.02 - 0.15; Algeria, proposed component; 0.026 - 0.13.)

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