THE SKOPJE, YUGOSLAVIA EARTHQUAKE OF JULY 26, 1963

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Much of the serious damage that resulted from the July 26 earthquake in Skopje, Yugoslavia might have been anticipated considering local code requirements and construction systems, designs, and practices prevalent there.

Although Skopje has an earthquake history dating back to Roman times, severe quakes occur only at very long intervals. The economy of Yugoslavia makes it expensive to design and build fully earthquake resistant structures. Instead, the design philosophy that existed was to erect buildings in such a way that loss of life may be minimized even though property damage might be large.

Skopje is the capital of Macedonia, (Fig. 1) one of six Yugoslavian states, and is located on the Vardar River. It is a center of transportation and communication and has experienced extensive growth in recent years. The population has increased from 49,000 in 1949 to approximately 200,000 in 1963 and as a result there is much modern construction (Fig.2) in addition to some ancient structures. Most of the damage from the July 26 quake occurred in the newer part of the city.

Seismological studies established that the July 26 quake had a magnitude of about 6 on the Richter scale and its intensity has been rated VIII to IX on the Modified Mercali scale.

The epicenter of the quake was located about seven to ten kilometers northeast of the city. Several fault lines are in the vicinity but the main one lies perpendicular to a line between Skopje and Kumanovo, a town located 38 kilometers northeast.

The earthquake left approximately 1100 persons dead and about 85 per cent of the people were left homeless. The majority of inhabitants as well as the city government offices had to be located in tents. There was some damage to water mains, but this was quickly repaired and no disease followed. Also, few fires accompanied the disaster.

Four types of construction are found in wide use in Skopje. Adobe construction is used for small homes and some damage and loss of life was experienced in these when tile roofs collapsed. However, most persons live in apartment buildings, usually built with load-bearing brick walls supporting concrete floor slabs. These masonry walls are unreinforced and

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are not tied in any way to the floors. Lime mortar is used throughout and these structures were designed for vertical loads only.

The quake occurred at 5:17 a.m. - at a time when the residential buildings were most highly occupied. As a result, most of the deaths occurred when the walls crumbled (Figs. 3 and 4).

A third form of construction is referred to by local engineers as "mixed construction". These buildings which account for only 5 per cent of new construction utilize reinforced concrete floor slabs supported partly by unreinforced masonry walls and partly by concrete columns. The masonry walls of many collapsed but loss of life was considerably less than in the wall-bearing structures because of the inherent strength of the remaining frame. A typical case is the warehouse shown in Fig. 5. Floor beams that had been supported by the exterior brick masonry wall were turned into cantilevers during the disaster. Although the resulting stress condition was completely reversed from that assumed in design, the frame itself did not fail.

The fourth construction system in use in Skopje is the reinforced concrete frame. Only two of these were reported to have collapsed. One was a two-storey structure designed and built by volunteer labor using donated materials, the other the shell roof of the Skopje Fair in which the four supporting columns were designed for vertical loads only. With these two exceptions there were no collapses of concrete frames in the city and no lives were reported lost in concrete frame structures. None were designed for earthquake forces although some were designed to withstand a wind force of about 20 psf.

Concrete frames are built both with and without concrete shear walls or cores. When used, these cores generally enclose elevators or stair wells. Framed structures without shear walls experienced nonstructural damage (partition wall and plaster cracking) at the ground floor, with damage progressively decreasing on upper floors.

A number of frames without shear walls in Skopje contained no masonry walls at ground level. Instead, ground floors were unenclosed or surrounded merely by glass. In these cases, the ground floor columns rotated at each end with accompanying spalling of concrete and sometimes permanent lateral displacement within the open ground floor. The reserve strength of these columns and their ability to continue to support the structure after going into the plastic range of the materials is illustrated in Fig. 6, a typical example of this type of performance. Fig. 7 shows a close-up view of a column of this kind.

When the ground floor of a reinforced concrete frame without shear walls was enclosed with masonry walls, structural damage throughout the frame generally was insignificant. Damage was experienced by partition walls in lower stories, again decreasing on upper floors.

When properly constructed, reinforced concrete frames with shear walls or concrete cores showed little or no structural damage. However, partition wall and plaster cracking was observed. When improperly constructed (i.e., when low-quality concrete was evident, when pipes or flues penetrated structural members in large numbers and when construction joints were faulty), structural cracking did occur in the concrete core and, at times, in the frame in lower floors. It should be noted, however, that core walls were for the most part completely unreinforced.

An apartment building in the Karpos area demonstrates typical performance of the concrete frame type of construction. (Fig. 8.) This structure contains 15 stories plus a penthouse. It was built with a reinforced concrete frame plus a concrete core that includes two elevator shafts (see Fig. 9). The core is unreinforced. The cast-in-place frame includes 4 $\frac{1}{2}$ inch thick one-way solid slabs. The building is supported by a single mat foundation that extends five feet beyond building lines at all four sides. Soil pressure under the mat is approximately 1.7 tons per square foot.

The building did not sway severely enough as to move furniture about. Diagonal shear cracking was observed above doorways that were located in the core. This type of cracking decreased from lower to higher floors. Diagonal partition wall cracking observed on many floors generally followed paths of embedded electrical conduits.

The southeast corner column failed, as shown in Fig. 10. However a core specimen taken from the column after the earthquake indicated a concrete strength of 2250 psi instead of 4250 psi required in the design. Two other identical structures in the Karpos area performed considerably better and experienced no structural distress.

Another example of a reinforced concrete frame building in Skopje was designed in a "Y" shape. (Fig. 11). This 11-storey apartment building, built in 1956, was reported to be the first high-rise structure in Skopje. As shown in Fig. 12, it contains a core, but this is of unreinforced concrete and extends only to the mid height of the second storey. Above this level the core utilizes only unreinforced brick masonry. The slab system is composed of precast single-T units simply supported on ledger beams.

Lateral load resistance is supplied by the shape of the structure, by reinforced concrete walls in each wing that contain chimneys, and by the action of the cast-in-place frame. Partition wall and plaster cracking were observed in the building but no structural damage occurred except for slight column distress at the outside corner of the southwest elevation.

The Trade Union Building, (Fig. 13) a 14-storey office building completed in 1962, was reported to be the best-performing tall building in Skopje. According to instrument observations made by the Technical University, the structure was not a millimeter out of plumb after the earthquake.

The structure utilizes a reinforced concrete frame (Fig. 14) plus three concrete core elements designed to carry all lateral loads. Cores are unreinforced except in the basement and first floor. All beams designed for vertical loads are continuous but without frame action with columns. The first floor and roof slabs are cast-in-place but other floors consist of precast joists and a cast-in-place unreinforced topping.

Joists are 10 inches deep by $2\frac{1}{2}$ inches wide and are reinforced with two 5/16 bars.

The building is founded on sand. Core walls and interior columns rest on a combined mat footing while perimeter columns carry their loads to individual spread footings.

During the earthquake, cleaning women reported being thrown to the floor and across the room. Furniture was strewn about. There was slight damage to elevator shafts but in general no structural damage of significance in the building. Partition wall and plaster cracking occurred and there was some damage to marble finishes on the ground floor. This damage resulted from a hammering of the tall structure against a shorter adjacent building.

The building code in Macedonia required no application of earthquake forces in design. However, taller structures were designed to resist wind forces.

The most common concrete design strength is 3100 psi at 28 days. For this class of concrete the allowable working stress for axial loads is 850 psi and for conditions of combined bending and axial loads is 1065 psi. For the lower storey columns of taller reinforced concrete frames, the design strength is 4250 psi. Slabs in wall bearing buildings generally utilize a concrete quality of 2300 psi at 28 days.

Reinforcing steel commonly used has an ultimate strength of 52,500 psi and is used with working stresses of 17,000 psi for bridges and 22,700 psi for other structures. Bars of 5/16 inch diameter and smaller may be used at a working stress of 25,500 psi in buildings only. A small amount of high strength steel having an ultimate strength of 73,000 psi is used for flexure only.

Allowable shear on concrete is 85 psi for concrete having a 28-day strength of 3100 psi. When shear stress is equal to 85 psi or less no shear reinforcement is required but common practice is to bend up 1/3 to 1/2 of the longitudinal steel. If the shear stress is above the 85 psi allowed, all shear must be carried by reinforcing steel. Very few shear-type cracks were observed in reinforced concrete frame members in Skopje.

Allowable bond stresses are equal to those given for shear; i.e., 85 psi for concrete having a 28-day strength of 3100 psi. All reinforcing bars are smooth and all are hooked. Only one bond failure was reported. This occurred in a column in a region of overlapping bars.

Customary practice in Skopje is to support structures on concrete mats or spread footings made of concrete with 28-day strengths varying from 1000 to 1500 psi. Allowable bearing pressure on sand and gravel varies from 2.5 to 3.0 tons per square foot and on clay from 1.5 to 2.0 tons per square foot. Piles are not used.

Job inspection in Skopje has been lax in recent years. Probably as a result of this, quality of concrete observed in many structures was poor.

Honeycombing was frequently seen due to insufficient cement paste, poor formwork or inadequate consolidation. Aggregate is secured for the most part from the Vardar river bed. Concrete fractures observed frequently passed around aggregate particles rather than through them, indicating a weak bond to the paste possibly due to coatings of silt and clay. In several instances debris such as wood blocks, rags and paper was found embedded in important structural members.

Typical distress conditions observed may be summarized as follows:

1. Inclined stairway slabs were frequently torn loose from floor slabs. This was because they were acting similarly to diagonals in a truss and were joined to floors by thin sections sometimes only $\frac{1}{2}$ inch thick.

2. Horizontal cracking was frequently visible on building elevations where the tops of masonry walls joined the undersides of spandrel beams. Masonry walls were not tied to frame members and were built with a weak lime mortar that was easily crumbled between fingers.

3. Partition wall cracking frequently followed lines of embedded electrical conduits.

4. Instances of hammering of short and tall structures against each other were observed.

5. Structures in which the ground floor was free of masonry walls frequently underwent a lateral displacement at the ground floor level.

Considering that seismic forces were not applied to structures during design and that construction methods were frequently substandard, it may be assumed that framed buildings performed well and in a predictable manner. The disaster emphasized that tall unreinforced masonry wall bearing structures without ties between walls and floors are unsuitable in seismic zones, especially if a weak mortar is used in joints.

Framed structures utilizing shear or core walls fared well when properly designed and constructed. Distress observed in structures of this kind may be related to insufficient lateral load resistance due to lack of shear wall reinforcement, poor construction practices and low-quality materials.

Frames without shear walls fared somewhat better when the ground floor was enclosed with masonry walls than when open because the masonry absorbed some of the lateral forces. However, there was nothing to indicate that structures with open ground floors should not perform well if proper consideration is given to this condition in the design.

The earthquake emphasized again that buildings should be properly spaced or jointed to prevent hammering of adjacent parts.

Horizontal cracking along cold joints observed in many structures stresses the importance of proper construction procedures and, as has always been true in disasters of this kind, the need for proper job inspection and adequate materials.

J. Amrhein presented a summary of this paper at the Session on Special Reports.

Figure 1. Map of Yugoslavia showing location of Skopje.

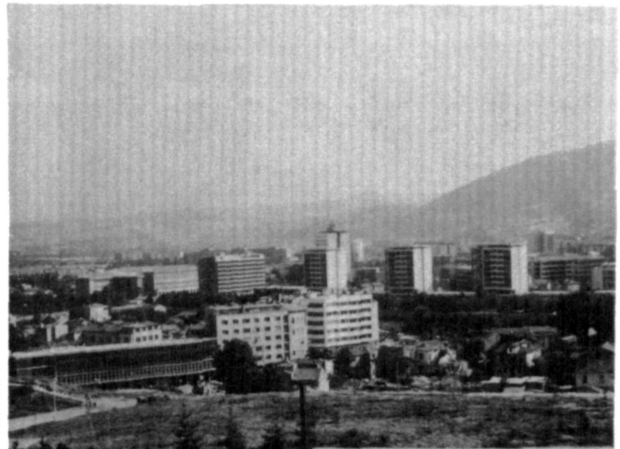
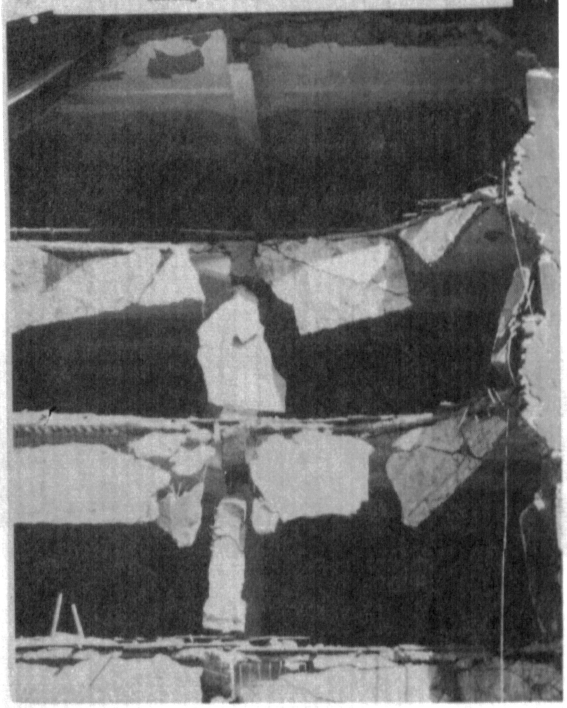


Figure 2. View of modern construction in Skopje.

Figure 3-4. Four story brick masonry apartments that collapsed.

Figure 5. Masonry wall fell away from floors of warehouse building. Concrete frame still support floor system.



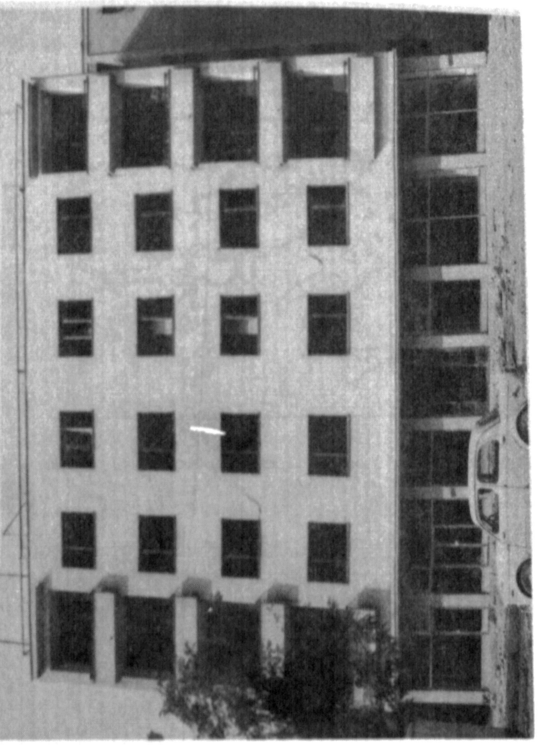


Figure 6. Five story permanently deformed with lateral drift.

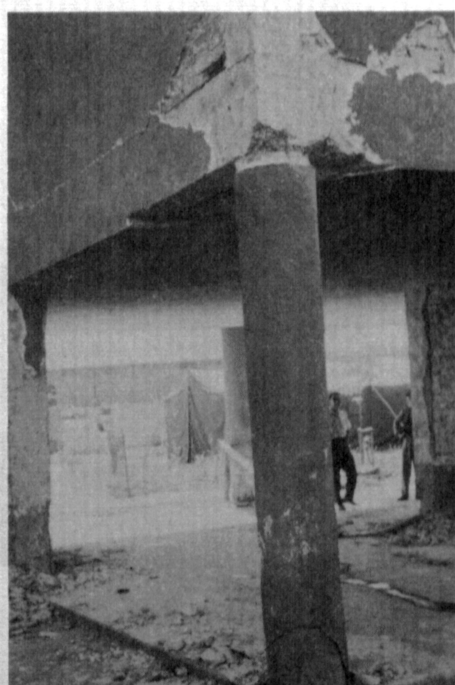


Figure 7. Rotation at top and bottom of column. Cement plaster coat spauled off.

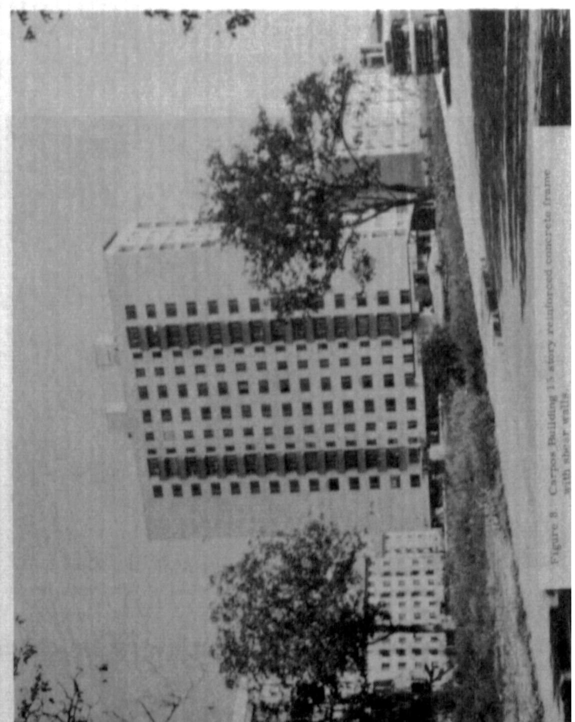


Figure 8. Carpos Building 15 story reinforced concrete frame with shear walls.

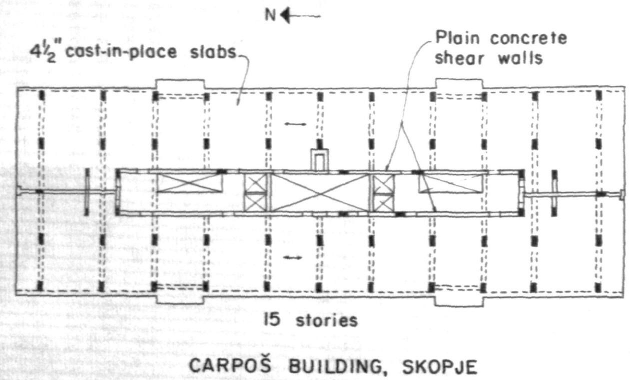


Figure 9. Plan of Carpoš Building.

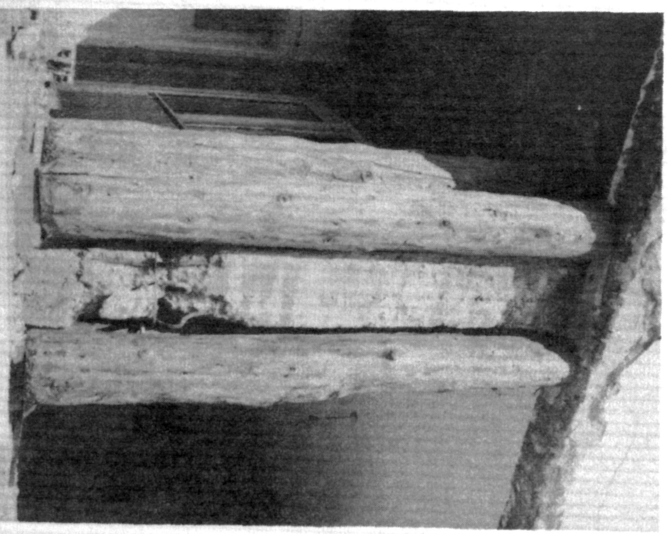


Figure 10. Southeast corner column failed. Concrete strength 2250 psi instead of 4250 psi required.

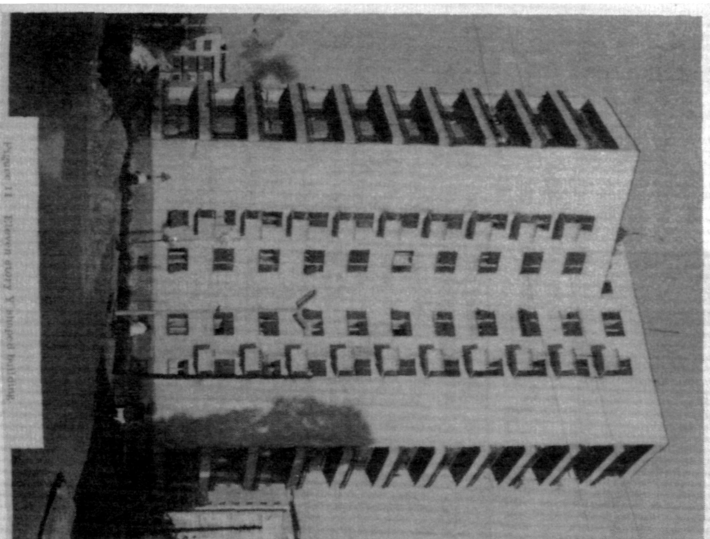


Figure 11. Eleven story Y shaped building.

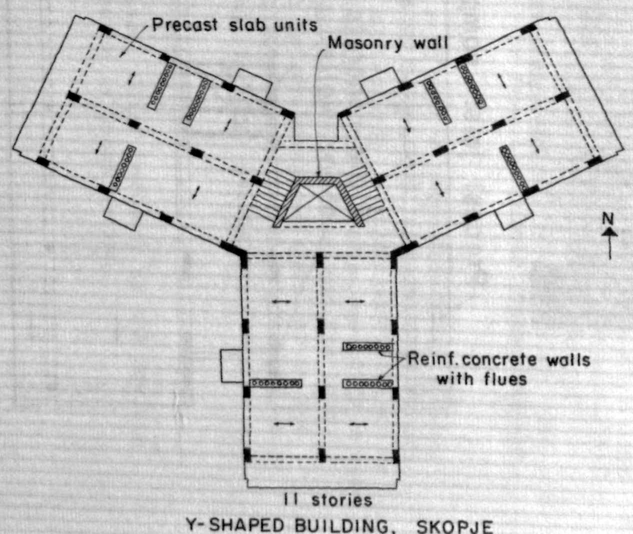


Figure 12. Plan of Y shaped building.

Figure 13. 14 story Trade Union Building.

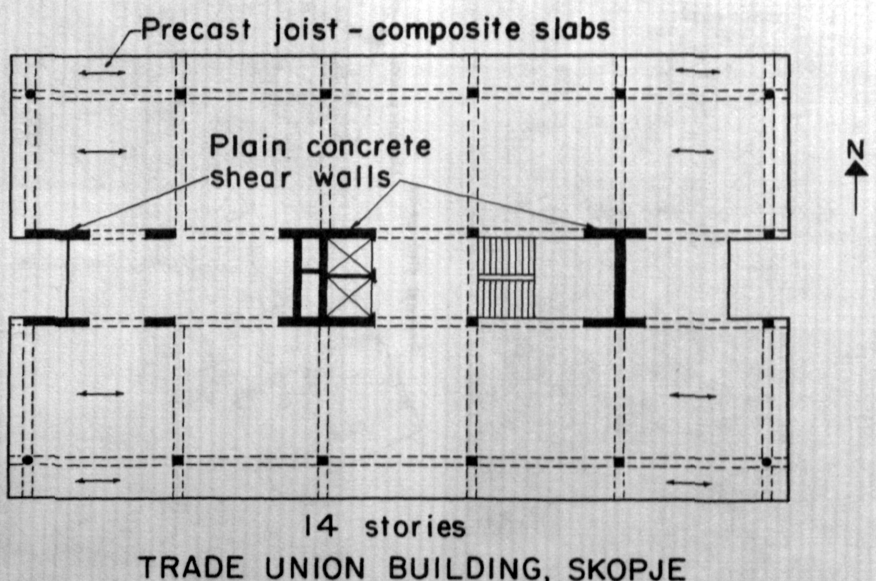


Figure 14. Plan of Trade Union Building.

SOME CONSIDERATIONS ABOUT THE SKOPJE EARTHQUAKE OF JULY, 1963

D I S C U S S I O N

BY J. DESPEYROUX

I was sent to Skopje by the UNESCO in an emergency mission, just a few days after the shock. My mission was to make a preliminary survey of the behaviour of the various buildings during the quake, and to give to Yugoslavian engineers some indications about earthquake resistant design and the reconstruction of town.

Among the questions which were to be quickly solved, the most important was to decide where Skopje was to be rebuilt. My opinion, confirmed later on by various experts, was that the town was to be rebuilt at the same place. I think it would be interesting to briefly explain the reasons for this decision.

The Vardar valley is a part of a large geological accident, several hundred miles long, going almost in a straight line from the Gulf of Salonique approximately to Rudnik, near Belgrade. This accident consists of a strip of mezozoical soils compressed between the old crystalline masses of Rhodope and Pelagonian Mountains. Every point along this accident must be considered as dangerous as another, so that it would have been of no interest to move the town along this line; this is demonstrated by the fact that the ancient town of Skupi (now called "Stari Skopje" : Old Skopje) having been destroyed by an eartnquake in 518, the fact that Skopje had been rebuilt at about two miles from the former place, did not protect it from seismic danger.

The only possibility was then to move Skopje perpendicularly to the valley. But, apart from the fact that it is generally nonsense to remove a town away from the natural site the suitability of which permitted it to grow, a displacement in a North-East direction for instance, would have had as a consequence, to reduce the distance between the town and the last observed epicentre. Thus, the seismic danger being not peculiar to the valley itself, it was decided to leave the town in the same place, special attention being paid for every building, to local geological features and local soil conditions.

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