FINITE ELEMENT MODELLING OF THE TURKISH-AEGEAN PLATE

Nuri Akkaş (I) and Kamil Eren (II)

Presenting Author : Nuri Akkaş

SUMMARY

In order to investigate the possible causes of the complex features of the stress state in the Turkish and Aegean plates, a two-dimensional finite element model of the region is developed. At present, the model is of a preliminary nature in the sense that no attempt is made to compare the numerically obtained stress state with that inferred from the focal mechanism and other geophysical information. The effects of various boundary conditions on the stress field are discussed.

INTRODUCTION

Turkey lies within the Mediterranean sector of the Alpine - Himalayan orogenic system. It is generally assumed that there is an active compressional motion taking place between the African and Eurasian plates and the Alpine orogeny is produced as a result of this motion. The seismic activities in the region are mostly concentrated along the microplate boundaries. The tectonic transport in the region is in the E - W direction. The first contact between the African and Eurasian plates took place in the Iranian sector. The northward compressional motion of the Arabian plate resulted in the lateral escape of the adjacent continental subblocks in a westerly direction. The Arabian plate is pushing the Van plate north and wedging the Turkish plate westward along the North Anatolian Fault, NAF,(Ref.1). The NAF is an active E - W trending right lateral strike - slip fault. The westward motion of the Turkish plate pushes the Aegean subplate towards the southwest.

Although McKenzie (Ref.2) treats the Turkish and Aegean plates as separate, the boundary between these two plates is rather poorly defined. McKenzie places this boundary slightly east of the E - W graben complexes of western Anatolia. However Alptekin (Ref.3) points out the shortcomings of this boundary by rejecting the mechanism with which such a boundary causes the graben system in the western Anatolia and, thus, he combines the two plates and calls it the Aegean - Turkish plate.

(I) Associate Professor of Civil Engineering,
Earthquake Engineering Research Center,
Middle East Technical University, Ankara, Turkey

(II) Assistant Professor of Civil Engineering,
Earthquake Engineering Research Center,
Middle East Technical University, Ankara, Turkey

Noting the uncertainties in the boundary between the Aegean and Turkish plates, here, in the present work, the two plates will be treated as a single unit. Such a treatment is acceptable for the purpose of this work which is to study the effects of various boundary conditions on the stress field in the region. A two-dimensional finite element model of the region is developed for this purpose.

THE MODEL

Several investigators have studied the tectonic stress field in some regions in the world by using the finite element method (Ref.4-9). The applicability of the method to various seismotectonic problems has now been well established. The equations to be solved are the classical elasticity equations. At present, viscous effects are not taken into consideration. The tectonic stress field in the region will be investigated using plane stress conditions. The thickness of the lithosphere is taken to be 130 km. The material is linearly elastic and isotropic. Young's modulus is 1.7×10^{11} ton / ($km.s^2$) and Poisson's ration is 0.25. The model and the finite element grid are shown in Figure 1. The number of plane stress elements is 71. Boundary elements are used along the boundaries of the model. Different stiffnesses have been assigned to the boundary elements in different runs of the computer program. The general purpose structural analysis program SAPIV (Ref.10) has been used in the numerical solution.

Eight types of models have been examined. In a previous work (Ref.11) five different models had been examined. Each model corresponds to a different boundary condition. The eight different models A through H are described in Table I.

Table I

Model / Boundary	A	B	C	D	E	F	G	H
NAF (AB of Fig.1)	SS	SS	SS	SS	RO	RO	RO	RO
Hellenic (AD of Fig.1)	RO	RO	FR	FR	RO	RO	FR	FR
Cyprus (DC of Fig.1)	RO	FR	FR	RO	RO	FR	FR	RO

SS : Simple support; the boundary node is restrained from translation in both directions.

RO : Roller; the boundary node is free to translate in tangential direction only.

FR : Free; the boundary node is free to translate in both directions.

The boundary conditions are changed by making the stiffnes of a boundary element zero or extremely large. There are no boundary elements along CB of Figure 1 because tractions are applied normal to this zone.

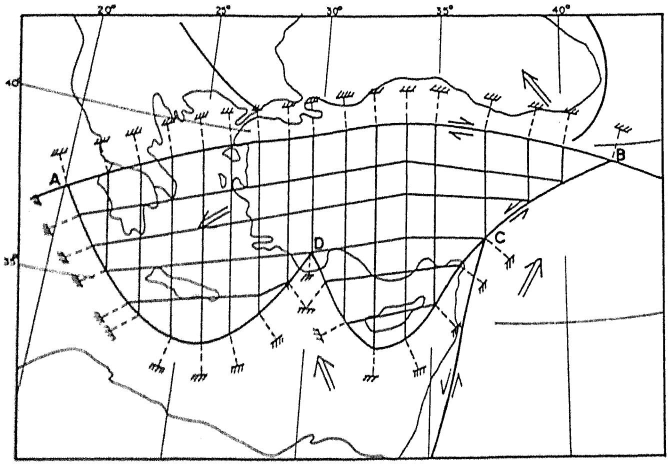

Fig. 1 The finite element mesh of the Turkish - Aegean plate

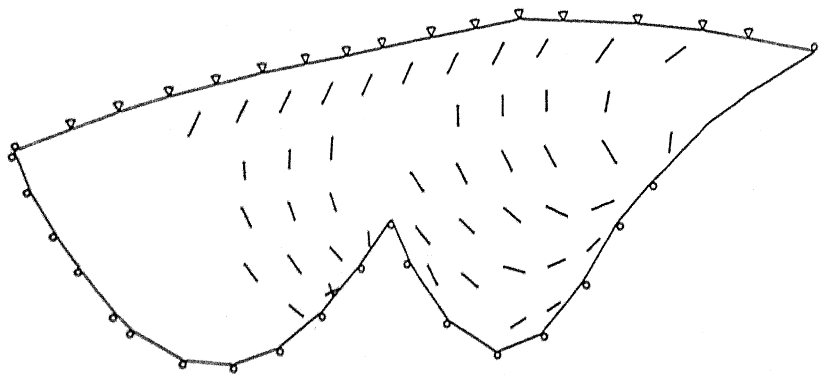

Fig. 2 Model A

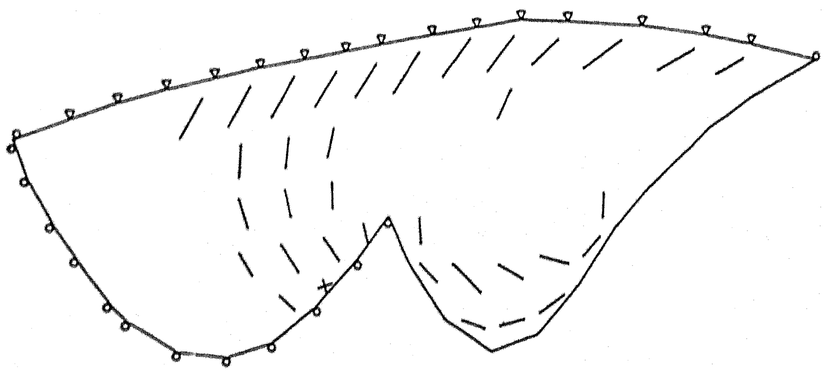

Fig. 3 Model B

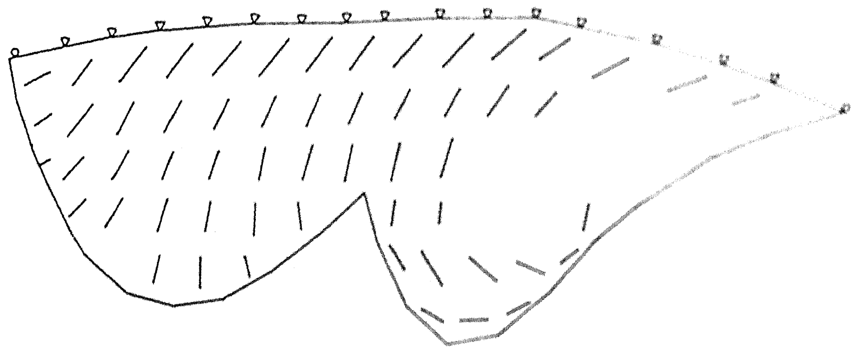

Fig. 4 Model C

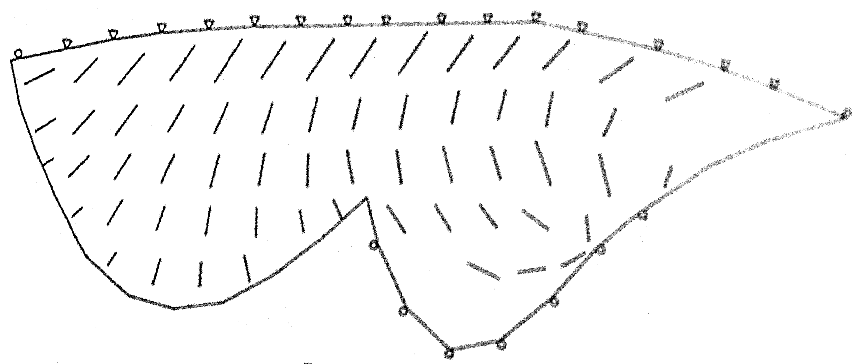

Fig. 5 Model D

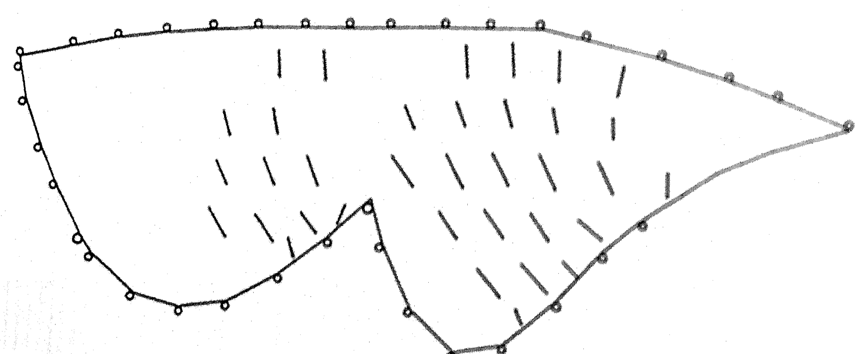

Fig. 6 Model E

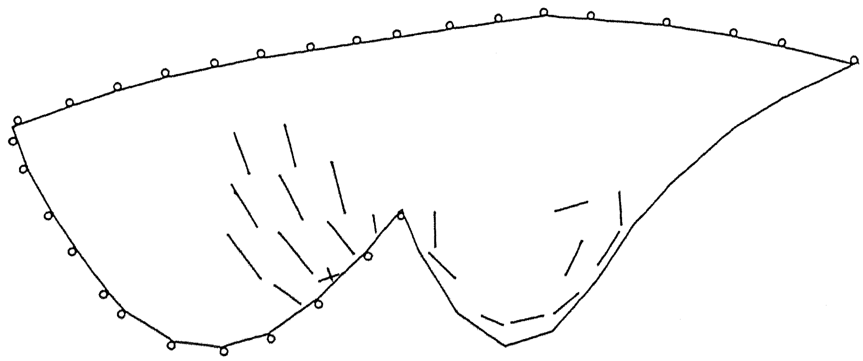

Fig. 7 Model F

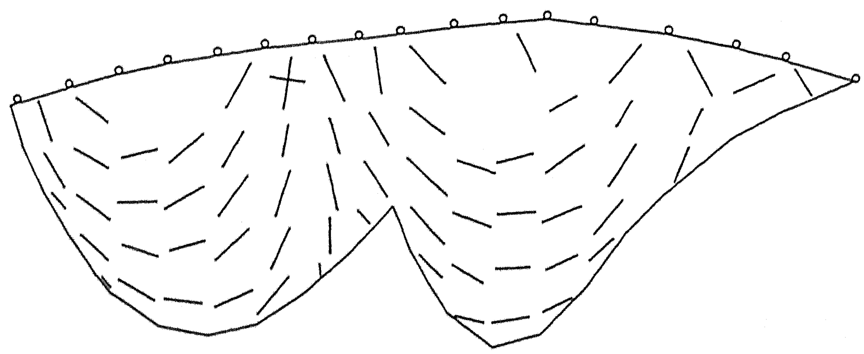

Fig. 8 Model G

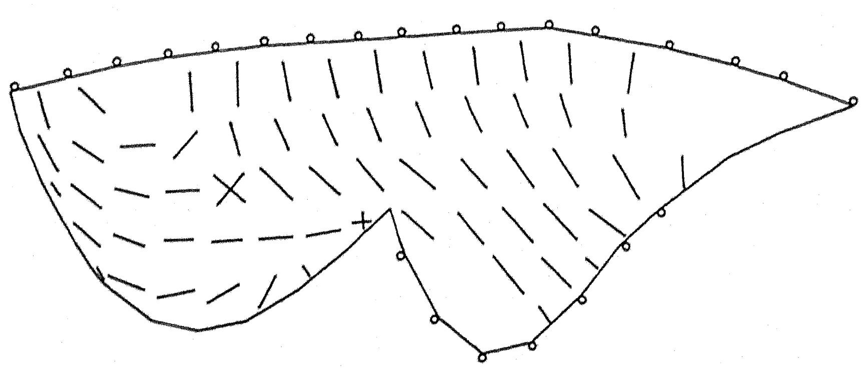

Fig. 9 Model H

As shown in Figure 1, the boundary of the Turkish-Aegean plate can be considered in four distinct parts. AB: North Anatolian Fault; BC : East Anatolian Fault; CD : Cyprus Arc; DA : Hellenic Arc. The tractions applied normal to the East Anatolian Fault Zone BC are supposed to simulate the compressive force that the Arabian plate is exerting on the Turkish plate. The magnitude of the force is irrelevant because the problem solved is a linear one.

RESULTS AND DISCUSSION

The qualitative results obtained from the eight models described above are presented in Figures 2 through 9. The principal tensile stresses at midpoints of the finite elements are shown in these figures. Quantitative results are not given because of the preliminary nature of the models. Moreover, the lengths of the principal tensile stress lines are not drawn in scale. Thus, by studying these figures it is only possible to get a general view of the stress distributions in the Turkish-Aegean plate. The most significant conclusions which are obtained from the numerical results are summarized below.

When the boundary nodes along the Hellenic Arc are restrained from translating in the normal direction (Models A, B, E, and F) the western portion of the Aegean plate is in a pure compression state. The fact that the boundary condition along the North Anatolian Fault is assumed to be simple support or roller does not change this observation. When the Hellenic Arc is allowed to translate freely in both directions (Models C, D, G and H) a much larger percentage of the Turkish-Aegean plate is subjected to tension. However, a comparison of the models C and D with the models G and H reveals the following fact. When the North Anatolian Fault is assumed to be simply supported (Models C and D) the tensile stresses in the Aegean plate turn out to be radial; whereas in the models G and H, in which the North Anatolian Fault zone is modeled with rollers the tensile stresses in the Aegean plate run roughly parallel to the Hellenic Arc. In all the models except for Model F Western Anatolia is always in tension in roughly N-S direction.

In models A through D the boundary nodes along the North Anatolian Fault are not allowed to translate in either direction. In models E through H, on the other hand, the same boundary nodes can translate in tangential direction. The former set of models (A through D) corresponds to the locked state of the North Anatolian Fault whereas the latter set (E through H) is apparently less realistic because it is known that the two faces of the North Anatolian Fault are not free to displace with respect to each other except during an earthquake. Indeed, the directions of the principal tensile stresses along the North Anatolian Fault zone shown in models E through H are not realistic either. In as much as the North Anatolian Fault is an east-west trending right lateral strike-slip fault, it is expected that the principal tensile stresses along this fault should roughly be in NE - SW direction. In models E through H this is not the case.

Under the assumptions that (a) the principal tensile stresses along the North Anatolian Fault zone should roughly be in NE - SW direction and (b) the principal tensile stresses in the Aegean plate should roughly be radial (i.e., normal to the Hellenic Arc), we can conclude that to model the boundary nodes along the North Anatolian Fault with rollers (as in Models E through H) is not realistic. Thus, if the above assumptions are valid the models E through H should be discarded from our discussion.

Going back to Models A through D in which the boundary nodes along the North Anatolian Fault are modelled as simple supports we see that the assumption (a) is satisfied in all four models. On the other hand, in Models A and B the western portion of the Aegean plate is in a state of pure compression. It is known that outward directed tractions (normal to the boundary) dominate along most of the Hellenic Arc (Ref.9). According to Ref.12 the driving force is possibly the difference in mass distribution due to the difference in elevation which is roughly 3 km between Aegean and the Mediterranean. Therefore, it appears that a state of pure compression in the western part of the Aegean plate is not realistic. In this case Models A and B can also be discarded from our discussion.

The results of Models C and D are generally alike except for the fact that in the former a large portion of East Anatolia is in a state of pure compression. On the other hand, in Model D the zone around Cyprus is in a state of pure compression. At present, due to lack of data, it is not reasonable to make a decision about which one of the two models is more realistic.

The models discussed in the present work certainly need to be improved. Research is continuing along this line. The most important conclusion of the present study may be that it is possible to decide upon the realistic boundary conditions of the model going through a systematic study of all possible cases and comparing the numerical results with the physical observations.

The number of elements used in the present form of the model may be not sufficient for a more detailed study. The fact that there were quite a few different models to be considered at this stage of the investigation put a restriction on the number of the elements used. However, now that this preliminary investigation has made possible to eliminate some of the models, it is feasible to use a larger number of elements in the future models as far as the computer time required is concerned. Moreover, rather than dividing the entire boundary of the Turkish-Aegean plate into four distinct zones only, namely the NAF, the Hellenic Arc, the Cyprus Arc, and the East Anatolian Fault, now it is also possible to make further subdivisions along the boundary. Finally, in the present work only one loading case has been considered. More realistic loading conditions can also be studied provided that substantiation through observations is obtainable. All these improvements shall be considered in future work.

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