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HIMALAYAN OROGEN-GANGA PLAIN FORELAND INTERACTION : A STUDY BASED ON FINITE ELEMENT MODELLING

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ABSTRACT

The collision between the Indian and Asian plates was simulated to analyze the stress pattern in the Indian lithosphere. We used Finite Element Method (FEM) for the 3-D modelling of the Indian landmass. The results of the modelling show a systematic variation in the values of both the tensile and compressive stresses throughout the Indian lithosphere from the hinterland of the Himalaya through the toe up to the distal part of the Ganga plain foreland basin. The distribution of the tensile stresses suggests the Lesser and Outer Himalayas are tectonically most active regions and are highly prone to seismic activity in the near future causing shallow-focus earthquakes as well as landslides.

Key words : FE Modelling, HImalaya, Ganga Plain.

INTRODUCTION

The continent-continent collision between the Indian and Asian plates during the Eocene time gave rise to the formation of the Himalayan mountain system. The thrust sheet loading in the Himalayan regions caused down-bending of the proximal part of the Indian lithosphere creating an asymmetric depression in front of it. Subsequently, this depression was filled by the sediments brought from the Himalayan Mountains by fluvial processes (Fraser and De Celles, 1992). The northward movement of Indian lithosphere is an ongoing process causing extensive neotectonic activity in the region of foreland basin and Himalayan orogen (Burbank, 1992; Singh, 1996; Agarwal *et al.*, 2002). The efffect of this movement and collision of Indian landmass have continuing effect in the form of landslide and earthquakes. The prediction of the extensive tectonic activity in the Himalayan region is a highly debatable and crucial aspect for the human settlement and development processes (Kumar *et al.*, 2001). In the present work an attempt has been made to simulate the Indian lithosphere model. Thus, the main objective of the present study is to evaluate the stresses in Indian Landmass due to the continent-continent collision using the Finite Element Method (FEM). This technique is used for obtaining the solution of a complex problem by dividing it into a collection of smaller and simpler problems that can be solved using numerical methods. It relies upon the rapid and accurate processing of vast quantities of data that are generated when a complex problem is subdivided into smaller subcomponent problems. The FEM has become a more popular tool with the advent of low cost, high-speed digital computers. To examine mechanical behaviour of a complex structure, its geometry is subdivided into small elements, which are interconnected at the points called 'nodes'. Furhtermore, loading, material properties and boundary conditios are provided and stress or strain magnitudes at each nodal point are calculated (Cook, 1978, 1994; Cook *et al.*, 1989, 2001; Bathe, 1982). The FEM technique has previously been used to calculate stresses and strains in civil, mechanical, aeronautical and biological structures (Young and Roark, 1989; Tenek and Argyris, 1997; Crisified, 1997; Keyak *et al.*, 1990; Muller and Ruegesegger, 1995; Koenigswald *et al.*, 1987; Rensberger, 1995 and Srivastava, 1998). In the present study the FEM has been helpful in modelling the areas of higher tesile and compressive stresses in simulated models of Indian lihosphere. There are few attempts to model the state of stresses in the foreland basin of the Ganga Plain (Parkash *et al.*, 2000), but this is the first attempt where FEM has been used to model the whole colliding Indian lithospheric plate in response to the Himalayan orogen, and therefore the study is of preliminary nature. This provides basic information on the identification of regions of maximum tectonic activity and landslide due to collision of Indian lithosphere due to its northward movement.

METHODOLOGY

For the present work, we used the Finite Element software, LapFEA, marketed by LapCad Engineering, San Diego, California, USA. The present study is a 3-D linear, elastic isotropic Finite Element Analysis (FEA) in which hexa elemtns are used to achieve the best results while investigating the nature of stresses occurring within the Indian lithosphere which has collided with the Sino-Siberian Platform. We analysed the stresses in the crustal part of the Indian plate. The mechnical properties of the heterogenous crustal rocks were not possible to determine and therefore the mechanical properties of most abundant crustal material , i.e. silica is considered for the present study. The mechanical properties like Young's Modulus, Poisson's Ratio values of silica at room temperature are considered for the evaluation of stresses (http://www.quartzunlimited.com). Additionally, the dimensions of Indian lithosphere were approximated at centimeter scale; however, a precise scale was not possible owing to the extensive dimension of Indian plate (aproximately 2400 km from east to west and 550 km from north to south) and (comparatively to the size) a very thin crust (approximately 70 km in Himalayan region). These limitations did not hinder the objective of the present study as the focus is on the relative distribution of tensile stresses rather than on the magnitude. We simulated a thin Indian plate having southern margin constituting 300 km wide Foreland basin and northern margin forming a 250 km wide Himalayan Region. The collision of Indian plate with The Asion plate and its northwad movement (approximately 5 cm/year) was simulated by anchoring the northern most portion of the model and by applying a constant force from southern margin of the plate. The direction fo the applied force was kept constant and considered more important than the magnitude of the force, which was selected randomly.

We calculated the distribution of tensile stresses and compressive stresses in Indian lithosphere. The maximum tensile stresses become more important while dealing mostly with the brittle material, i.e. loose sand (silica). According to the material theory (Cook, 1994), a ductile metal rod undergoes dislocation when subjected to axial tension. It undergoes plastic deofrmation at the first place before showing brittle deformation (in the form of fracturing), which indicates that discrete shearing has occurred. In this process the rod becomes thinner (due to extension) in the region of the dislocation and finally the fracture occurs in this region due to the concentration of the stresses. On the other hand, if a brittle rod is subjected to tension, it breaks instantly without any prior (visible) plastic deformation. In contrast to the plastic deformation due to shear

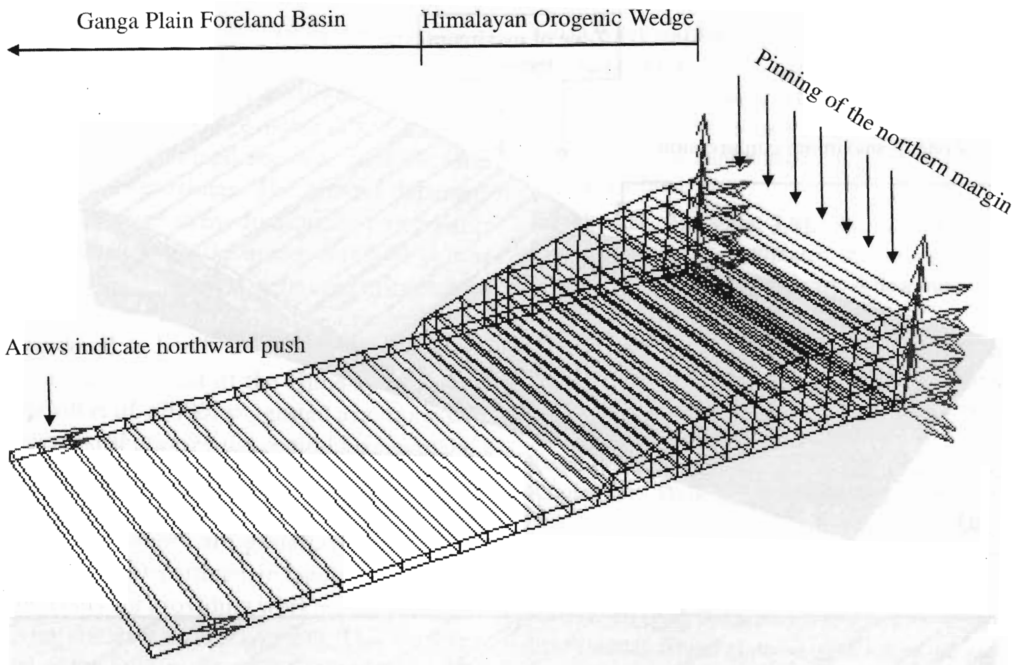


Fig. 1. Schematic diagram representing FEM model of the Indian Lithosphere along with the Himalayan Orogenic wedge (based on Agarwal *et al.*, 2002)

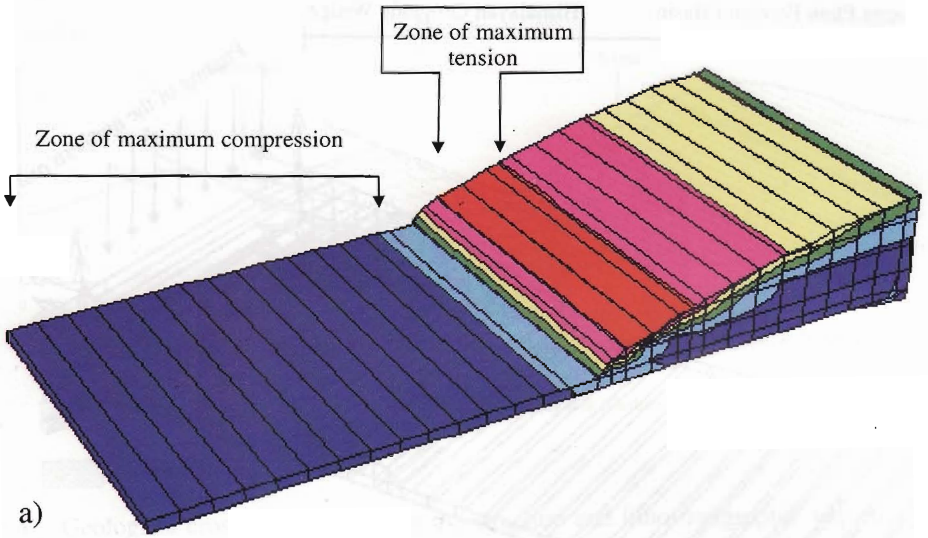
stresses, the maximum tensile stresses are the crtieria for fracture in brittle material (Kingery *et al.*, 1976). The brittle material is stronger under compression than tension (Cook, 1994), because in compression the atoms come close to each other whereas in tension they pull apart.

OBSERVATIONS

On applying constant pressure on the southernmost margin of the Indian plate (fig. 1), a systematic variation in the distrubution of tensile and compressive stresses is observed throughouth the Indian lithosphere (from the hinterland of the Himalaya to the toe, up to the distal part of the Ganga plain foreland basin) (fig. 2). The peak tensile stresses are concentrated in the shallow surface (2-5 km) along the piedmont zone, lesser and central part of the Himalayan Region (fig. 2). As we go deeper under the surface the tensile stresses decrease and deeper part of Himalayan region mostly experiences compressive stresses. The peak compressive streeses are concentrated away from the Outer Himalayan fold thrust belt and the Central and Marginal parts of the Foreland Basin.

DISCUSSION AND CONCLUSIONS

Finite Element Modelling seems to be a very effective tool to understand the state of stress distribution in an object that is subjected to the load. This has been found to be much useful in studying the nature of stress distribution in one of the most geologically fragile regions of the world. The results lead to the conclusion that the zone of maximum tensile stresses is where the Himalayan wedge seems to grow vertically. The foreland part of the



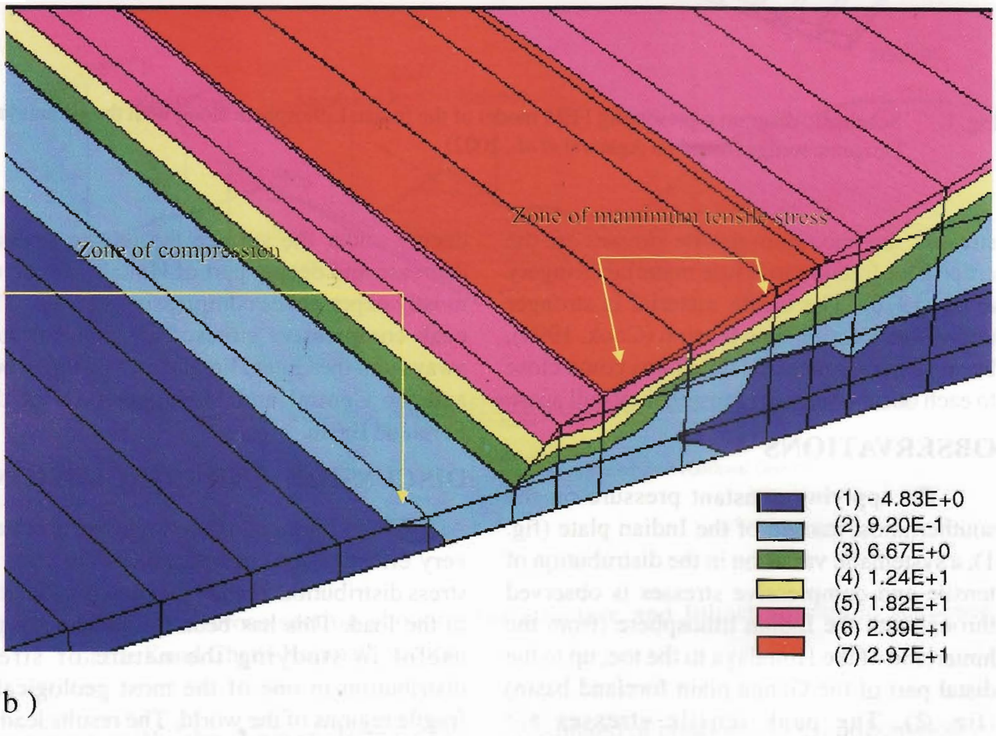


Fig. 2. a) FEM model showing the distribution of stresses within the Himalayan Orogenic wedge due to the northward push of the Indian Plate; b) enlargement of the model towards the foreland.

Himalayan system, according to the present study, shows a uniform distribution of compressive stresses. The supracritical nature of the Himalayan wedge makes this region more prone to frequent land degradation in the form of massive landslides. The present departure in the pattern of stress distribution (Agarwal *et al.*, 2002) especially in the foreland part is attributed to the fact that in the current modelling program the Indian lithosphere has been considered as bending (arching down) under the increasing load of the Himalayan wedge. Parkash *et al.* (2000) suggested a compressive stress distribution in the central Ganga plain.

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