

# **MECHANICALLY FASTENED COMPOSITE LAMINATES SUBJECTED TO COMBINED BEARING-BYPASS AND SHEAR LOADING**

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## **Abstract**

Bolts and rivets provide a means of load transfer in the construction of aircraft. However, they give rise to stress concentrations and are often the source and location of static and fatigue failures. Furthermore, fastener holes are prone to cracks during take-off and landing. These cracks present the most common origin of structural failures in aircraft. Therefore, accurate determination of the contact stresses associated with such loaded holes in mechanically fastened joints is essential to reliable strength evaluation and failure prediction.

As the laminate is subjected to loading, the contact region, whose extent is not known, develops between the fastener and the hole boundary. The fastener exerts loading on the hole boundary through this contact region, which consists of slip and no-slip zones due to friction, Figure 1. The presence of the unknown contact stress distribution over the contact region between the pin and the composite laminate, material anisotropy, friction between the pin and the laminate, pin-hole clearance, combined bearing-bypass and shear loading, and finite geometry of the laminate result in a complex non-linear problem. In the case of bearing-bypass loading in compression, this non-linear problem is further complicated by the presence of dual contact regions.

Previous research concerning the analysis of mechanical joints subjected to combined bearing-bypass and shear loading is non-existent. In the case of bearing-bypass loading only, except for the study conducted by Naik and Crews (1991), others employed the concept of superposition which is not valid for this non-linear problem. Naik and Crews applied a linear finite element analysis with conditions along the pin-hole contact region specified as displacement constraint equations. The major shortcoming of this method is that the variation of the contact region as a function of the applied load should be known a priori. Also, their analysis is limited to symmetric geometry and material systems, and frictionless boundary conditions. Since the contact stress distribution and the contact region are not known a priori, they did not directly impose the boundary conditions appropriate for modelling the contact and on-contact regions between the fastener and the hole. Furthermore, finite element analysis is not suitable for iterative design calculations for optimizing laminate construction in the presence of fasteners under complex loading conditions.

In this study, the solution method developed by Madenci and Ileri (1992a,b) has been extended to determine the contact stresses in mechanical joints under (a) combined bearing-bypass and shear loading, (b) bearing-bypass loading in compression resulting in dual contact regions.

In the absence of shear loading, bypass loading has a significant effect on the contact stresses and contact angle. As shown in Figure 2, the peak stresses and the contact angle decrease for increasing bypass loading. The influence of shear loading is captured in Figure 3. It results in an asymmetric stress variation with higher peak value than that of without shear loading. However, the effect of shear loading on the remaining stress components and the contact angle is negligible. The influence of bypass loading in the presence of shear loading is shown in Figure 4. As expected, the variation of contact stresses is asymmetric and that the contact angle decreases for increasing bypass loading. Bearing-bypass loading in compression results in two contact regions, side-A and side-B corresponding to the applied and bypass loads, respectively. For a bearing-bypass ratio of 2, the contact stresses and the contact angles are presented in Figure 5. A significant portion of the contact region is in compression and that the stress concentration is lower than that of the unloaded hole case. In this study, the specimen geometry is specified by these parameters:  $L=292$  mm,  $H=203$  mm,  $R=25.4$  mm,  $I=191$  mm,  $h=101.5$  mm,  $\lambda=.508$  mm. The material is quasi-isotropic with lamina properties:  $E_L=37.2$  GPa,  $E_T=12.3$  GPa,  $G_{LT}=3.93$  GPa,  $\nu=.3$ .

It can be concluded that the effect of bypass loading and bearing-bypass loading in compression is favorable for efficient joint design. However, the presence of shear loading results in a higher tangential peak stress; thus, it reduces the strength of the joint. Also, these results illustrate the capability of this solution method for computing contact stresses in pin-loaded holes under various loading conditions while capturing the effects of friction, free edges, end distance, pin-hole clearance, and material anisotropy on the contact stresses.

#### References:

- Naik, R. and Crews, J. H., Jr., 1991, "Stress Analysis Method for Clearance-Fit Joints with Bearing-Bypass Loading," *AIAA Journal*, Vol. 29, pp. 89-95.
- Madenci, E. and Ileri, L., 1992a, "Analytical Determination of Contact Stresses in Mechanically Fastened Composite Laminates with Finite Boundaries," *International Journal of Solids and Structures* (in press).
- Madenci, E. and Ileri, L., 1992b, "Contact Stresses and Stress Intensity Factors for a Pin-Loaded Hole with Edge Cracks in Finite Orthotropic Laminates," *ASME Journal of Applied Mechanics* (accepted for publication).

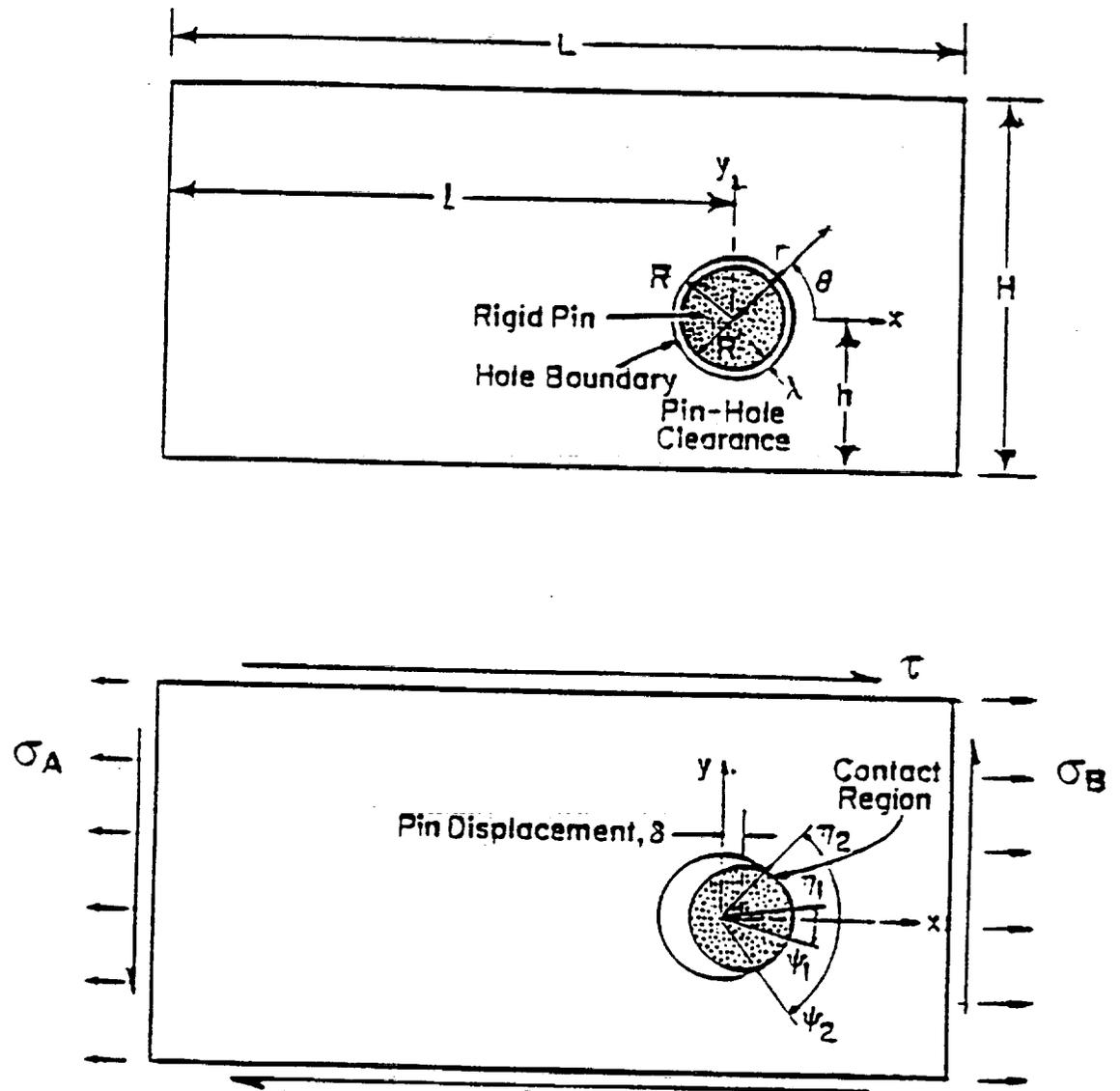


Figure 1 Position of the fastener before and after deformation

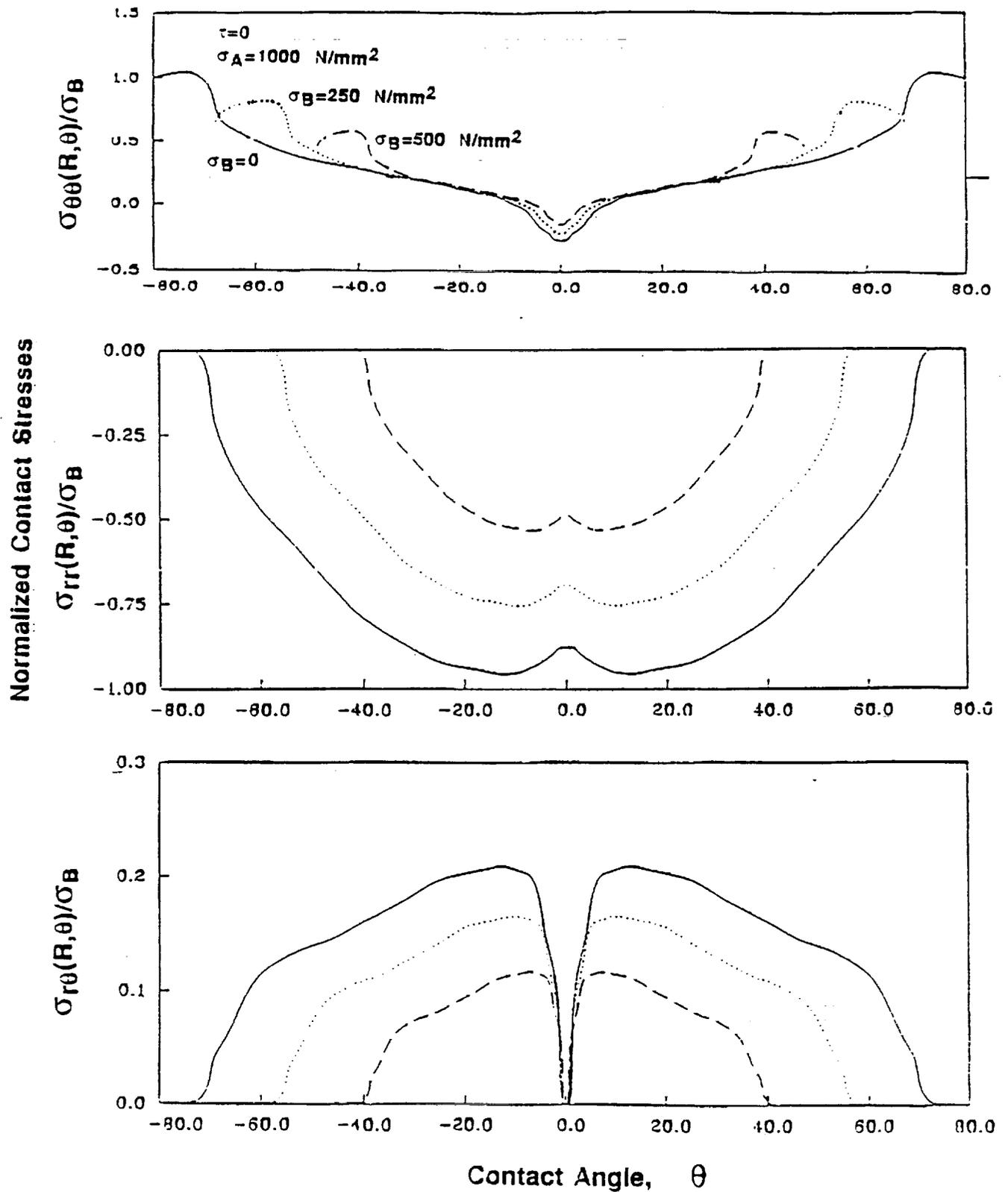


Figure 2 Variation of contact stresses for a range of bypass loads in the absence of shear loading

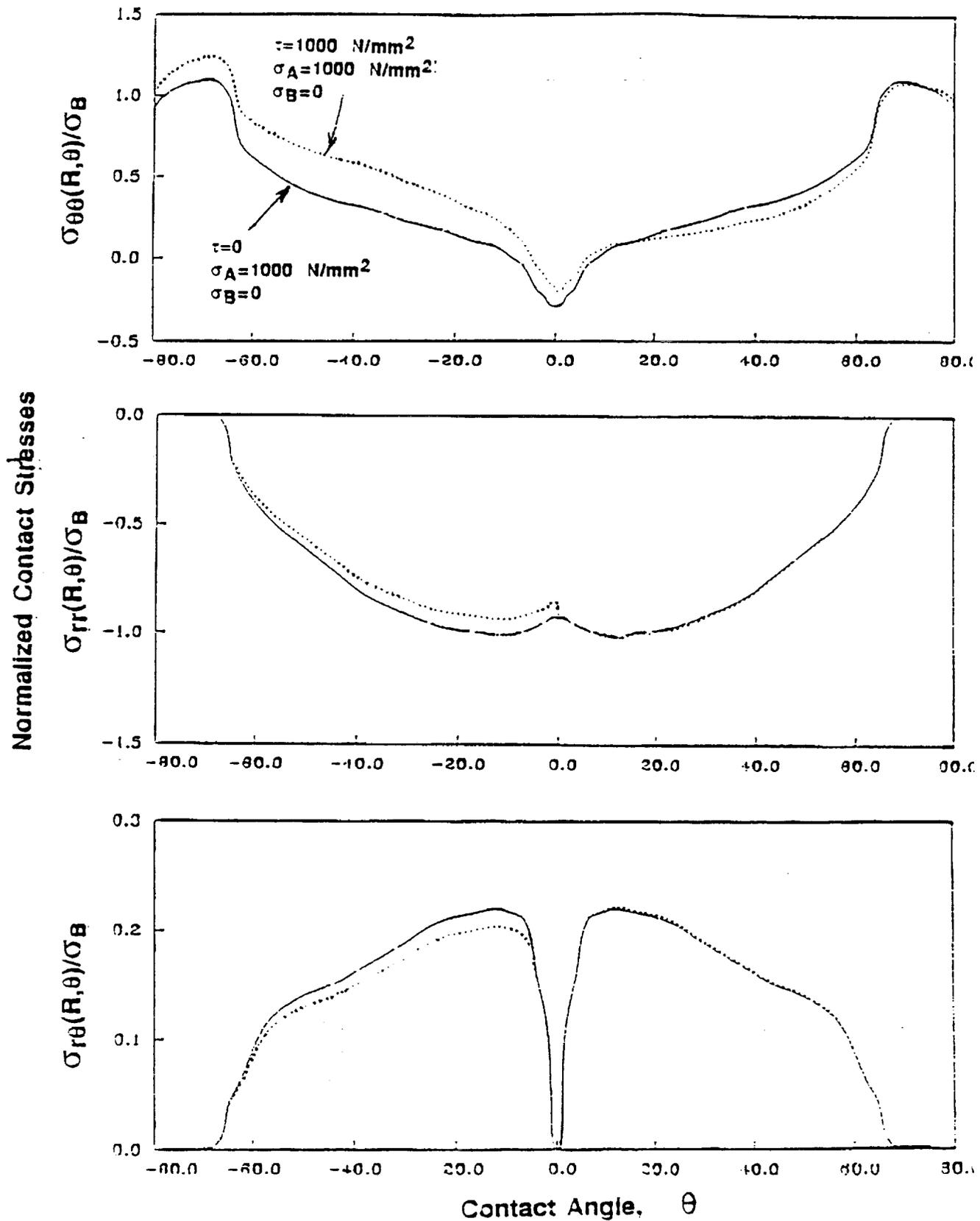


Figure 3 The effect of shear loading on the contact stresses in the absence of bypass loading

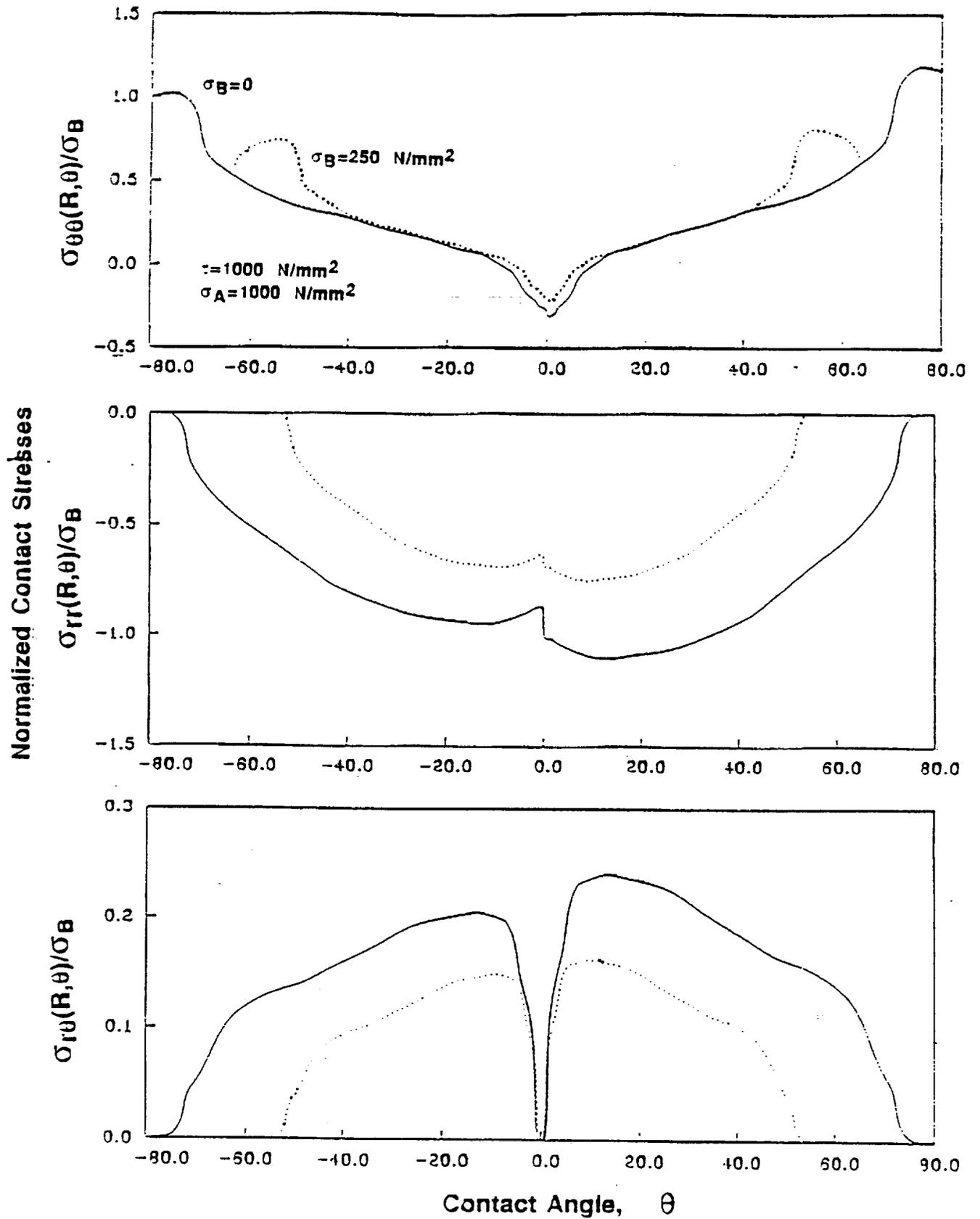


Figure 4 Variation of contact stresses for combined bearing-bypass and shear loading

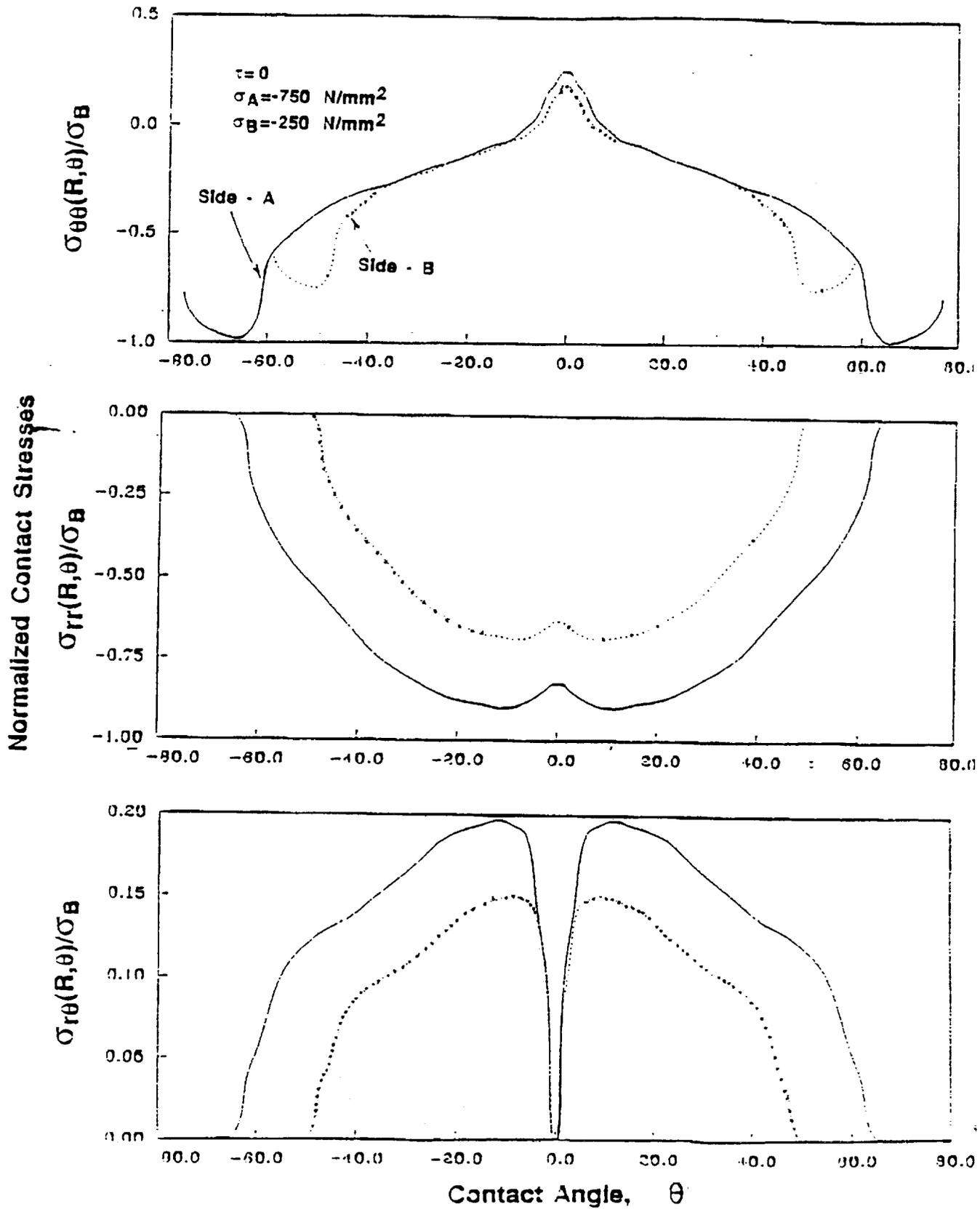


Figure 5 Variation of contact stresses on each side of the fastener when bearing-bypass loading is in compression