TRANSFERRING LOAD TO FLESH
PART VI. SOCKET BRJM RADIUS EFFECTS

Leon Bennett, M.A.E.
Senior Research Scientist

Center for Interdisciplinary Programs
New York University
West 177th Street and Harlem River, Bronx, N.Y. 10453

ABSTRACT

The effect of socket brim radius upon that flesh in proximity to the socket is gaged experimentally. Simulated flesh (Spence Gel) is loaded by various sections representing slices of an above-knee socket. The output, in the form of local compressive and shear stress, within the simulated flesh, is presented as a function of brim radius.

It is shown that while increasing the brim radius will reduce the compressive stress local to the brim, stress levels elsewhere will be raised. Shear stress also reacts in a trade-off fashion. The optimal brim radius is roughly 1/2 in., a value in accordance with common socket design standards.

INTRODUCTION

Our long range concern is with reducing the incidence of soft tissue trauma attributable to mechanical stress. Our immediate goal is to determine the stress levels associated with common forms of prosthetic and orthotic loading of flesh, so as to supply useful recommendations to designers and other workers in the field.

While this article is complete in itself, certain of the background concepts and details given in prior work will be found useful in achieving a full understanding of the material; these are not repeated here. The interested reader is referred to previous papers in this series for a qualitative discussion of stress factors in soft materials (1), an analytic treatment of compressive stress in flesh under varied loading conditions (2), an analytic treatment of the

[a] Based on work performed under VA Contract V101(134)P–18.

shear stress developed within flesh under varied loading conditions (3), an analytic treatment of the shear and compressive stresses produced by pressing a hemispherical button into flesh (4), and a comparison of analytical and experimental techniques (5).

In this article, we are concerned with the stress effects, both shear and compressive, produced when a prosthetic socket segment (patterned loosely after a standard above-knee socket) is pressed into thick flesh supported by a bone. In effect, a two-dimensional slice of socket, flesh, and bone is being tested. At issue is the influence of brim radius.

Socket brim radius values frequently represent a compromise between conflicting goals. A large radius is usually viewed as a sound means of relieving local flesh strain owing to loads perpendicular to the socket; for example, an above-knee socket subject to horizontal load would ideally employ large brim radii to minimize the stresses due to horizontal load. However, a large radius prevents the transfer of vertical load. In the case of an above-knee socket, too large a brim radius will result in the ischium sliding into the socket with consequent loss of vertical off-loading at the ischial seat. A practical value of radius at the anterior edge of the ischial seat has been given as 1/2 in. by Hanger (6).

The example given above, illustrating the necessity for compromise brim radius values, is somewhat special. Frequently, the brim radius may be of any reasonable value.

In this work brim radius is the variable under study. The condition simulated (Fig. 1) is one where a portion of socket, flesh, and bone is subject to a fixed horizontal load (1.1 lb.). There is no vertical load. The situation simulated corresponds to the loading of an anterior portion of an above-knee socket. At issue are the stresses generated in proximity to the brim and specifically, the manner in which these stresses vary as a function of brim radius.

The basic question to be answered is: does brim radius really matter in terms of flesh stress? If so, is there an optimal radius?

METHOD OF PROCEDURE

The techniques employed are purely experimental and have been given in some detail previously (5). The experimental approach was chosen over the analytical because the experimental is simpler; any desired socket contour may be shaped and tested quickly. In contrast, analytical treatment of arbitrary contours is laborious. There is no reason to believe that either approach is inherently the

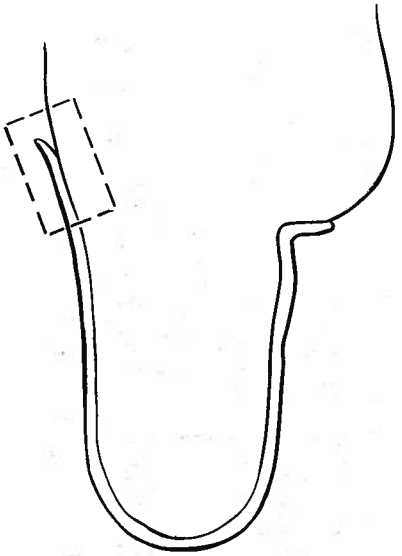

FIGURE 1.—Socket-stump loading schematic. The portion within the dashed rectangle is stimulated in this work.

more accurate; both are simulations with certain shortcomings as given in reference 5.

This work differs from reference 5 in that we are here concerned with the solution of a particular prosthetic problem, whereas previously we have been concerned with establishing a technique capable of such solutions. While reference 5 contains solutions for stresses arising in flesh owing to various loading factors, the choice of loading factors was governed by the availability of corresponding theoretical solutions, thus permitting a theory versus experiment check. Unfortunately, many of the loading factors so chosen are not useful; for example, the dull chisel case is hardly practical. Having shown that the experimental technique for flesh stress determination has merit, we are now able to move on to practical work.

In briefest summary, the experimental technique employs as a flesh model a sandwich of Spence Gel between foam outer covers. The sandwich is placed between rigid, transparent plastic walls. A contour of interest is carved in balsa wood and inserted between the walls so as to impinge on the model flesh. The contour is loaded as desired—in this work a constant load (1.1 lb.) is employed. Deflection of the model flesh is shown by changes on a grid system marked on the foam. Photographs of model flesh grid deflection are evaluated by means of an optical comparator (loupe plus graduated reticle) in terms of grid element spacing (compressive strain) and grid element angularity (shear strain). Conversion of strain to stress is accomplished through calibration of the model flesh.

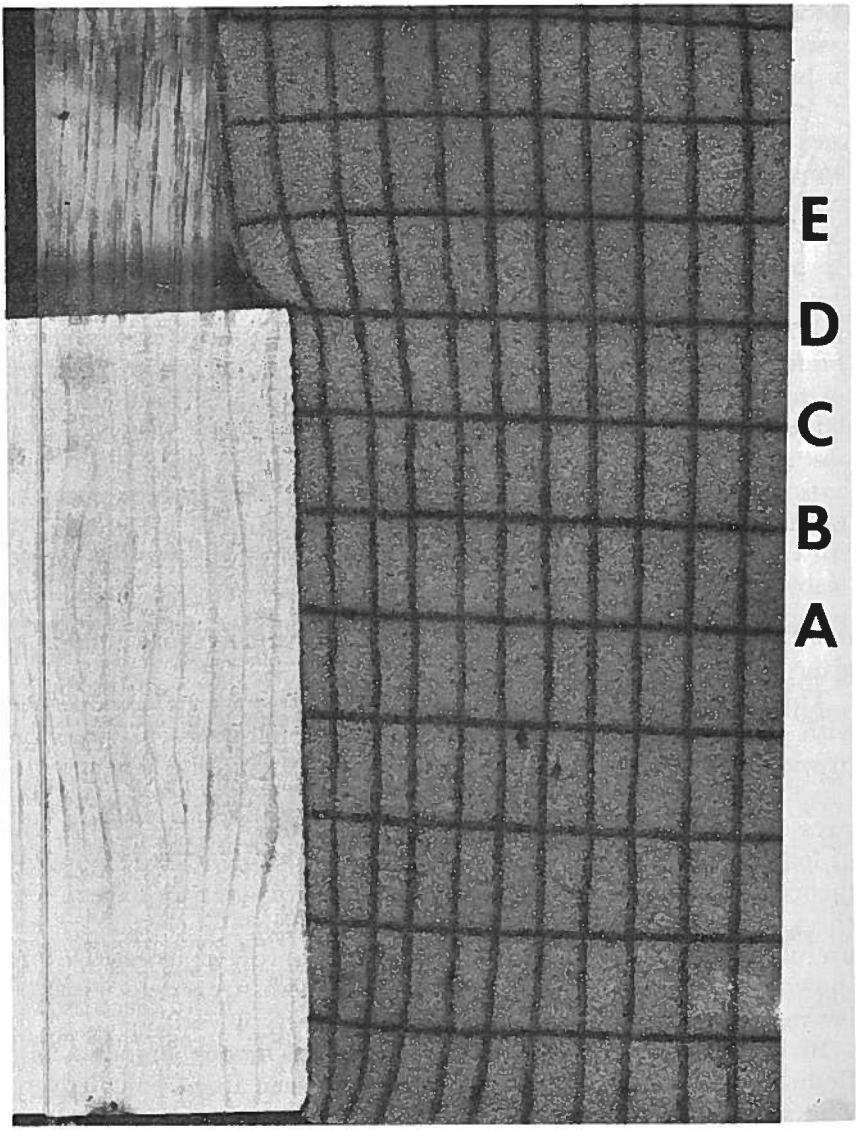

FIGURE 2.—Result of right angle corner brim test. The corner under test is at the upper end of the block. Note sharp change in flesh model contour, indicating severe strain, at corner.

RESULTS

Certain of the raw data are given as Figures 2, 3, and 4. Figure 2 shows the results of loading a brim with a right angle (no radius) corner at the right-hand side of the block. The corner radius under test in Figure 3 is 1/2 in. and that shown in Figure 4 is 1 in.

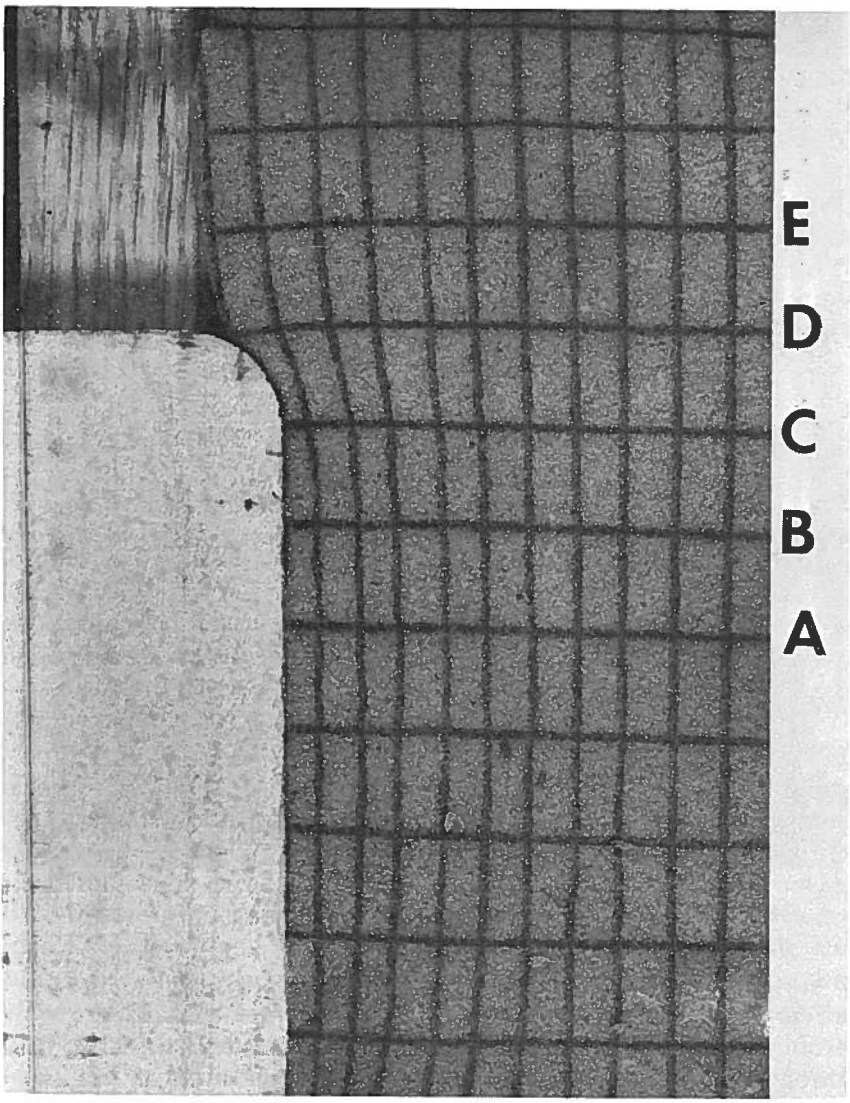

FIGURE 3.—Result of ½-in.-radius test. Note distortion of model flesh near brim.

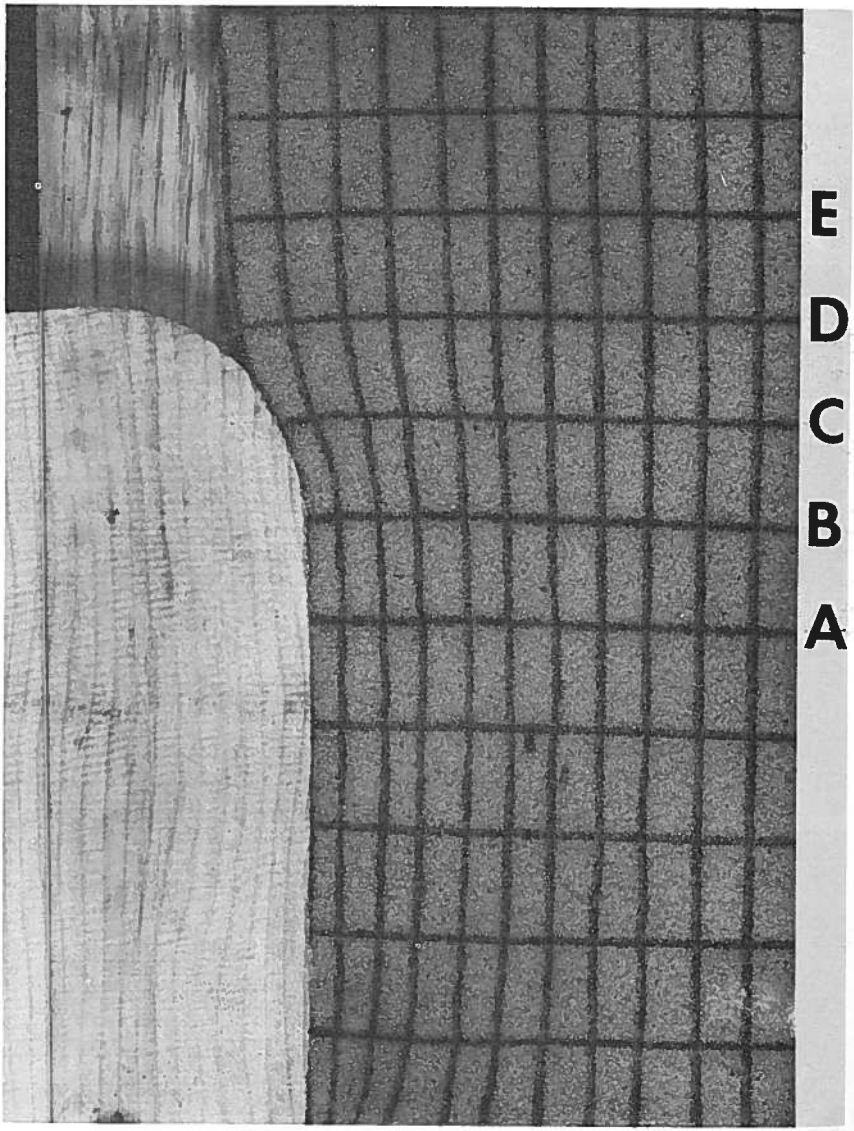

FIGURE 4.—Result of 1-in. radius test. Major stresses still occur near brim.

Casual inspection of these data indicates that the compressive stress (indicated by compressive strain or flatter rectangles) remote from the corner and under the member is essentially the same in all three cases. The shear stress (indicated by shear strain or the extent of departure from a right angle at intersecting grid lines) also remote from the corner and under the member approaches zero.

Differences occur largely in the vicinity of the corner. In other words, brim radius effects are local and do not alter the stress distribution deep into the socket. They do, rather dramatically, alter by substantial amounts stresses in the section just outside the socket.

Compressive Stress

Analyzing the data for normal stress (compressive) produces those results of Figures 5, 6, and 7, where Figure 5 is that outcome of data shown in Figure 2; Figure 6 is similarly related to Figure 3, and Figure 7 to Figure 4. In presenting results, the initial depth (unloaded) is employed as the abscissa and the normal stress given as the ordinate. The stresses along certain arbitrary lines (A, B, C, D, E), located as indicated with respect to the brim, supply a sense of the variation of stress with respect to brim proximity and depth within the flesh. Each of the imaginary lines cuts through the full flesh depth joining the "bone" to the "socket." Line separation is 0.4 in., and line D is chosen to coincide with the socket edge; A, B, and C existing within the socket and E in that unrestrained flesh above the socket.

Examining line A of, say Figure 5, we note that the compressive stress increases towards the loaded member (socket) or decreases moving towards the "bone," i.e., base. In other words, curve A stress values decrease as depth increases. Lines B and C of Figure 5, still well within the socket, display values nearly identical to A. At the corner itself, D line, sufficient flow occurs remote from the socket (say 1 in. deep) to relieve the compressive stresses considerably. At station E, 0.4 in. above the socket, the compressive stress is almost entirely unloaded.

Moving to a 1/2-in.-corner radius (Fig. 6), it is seen that stress values along lines A, B, and C are but little changed from those associated with a right angle corner (Fig. 5). In other words, the change of corner radii values does not produce a corresponding change in normal (compressive) stress values deep in the socket. However, a significant reduction of stress does occur locally (line D, small unloaded depth values) at the corner itself. Above the socket (line E), the stress values associated with the 1/2-in.-corner radius are increased as compared to right angle corner values. While the magnitude of the stress increase is small, it is significant. Noting that an *overall* reduction of stress *cannot* occur as a result of altering the corner radius (the necessity for equilibrium dictates that any local reduction in stress be offset by a corresponding increase elsewhere), it would appear that the price for stress value reductions along line D are increases along line E.

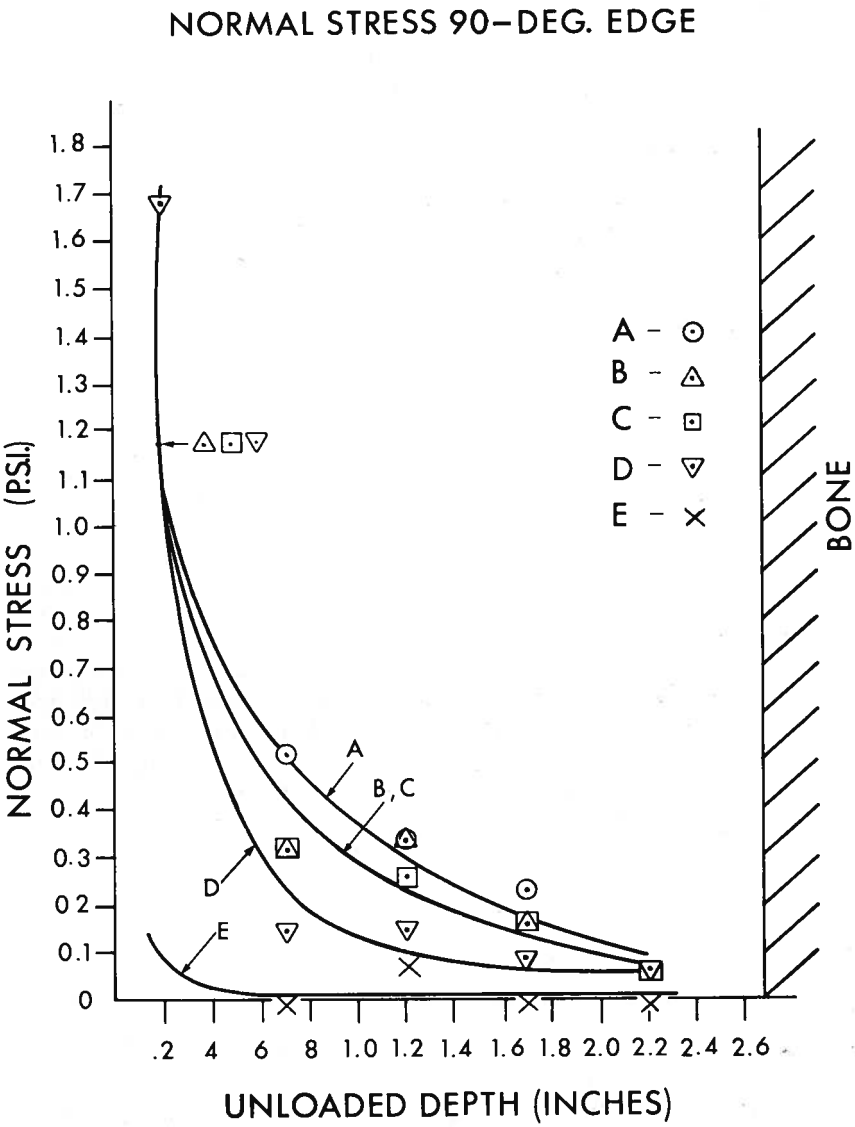

FIGURE 5.—Compressive stresses resulting from right angle corner test shown in Figure 2.

When a 1-in.-corner radius is employed (Fig. 7), the basic trends continue. Thus, lines A, B, and C remain nearly identical in values; lines D and E are relatively unloaded. To unload line D, it has become necessary to correspondingly increase stresses within the socket. Therefore, at shallow depths, lines A, B, and C display

significantly higher stresses than those values associated with sharper corners.

Shear Stress

Shear stresses along lines A and B are essentially zero throughout this test series and are not given as plots. The low values reflect the similarity of compressive stresses along lines A and B; it has been shown previously (3) that shear stress is proportional to the gradient

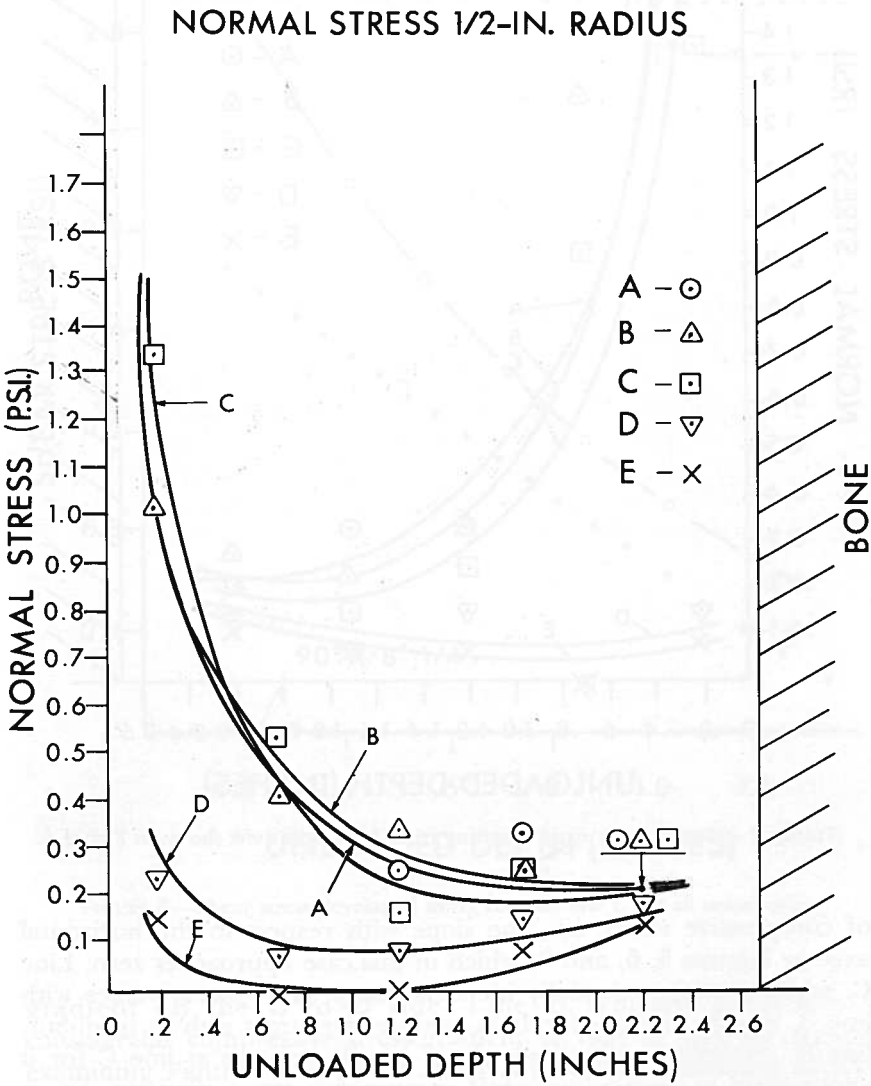

FIGURE 6.—Compressive stress resulting from ½-in-.-radius test shown in Figure 3.

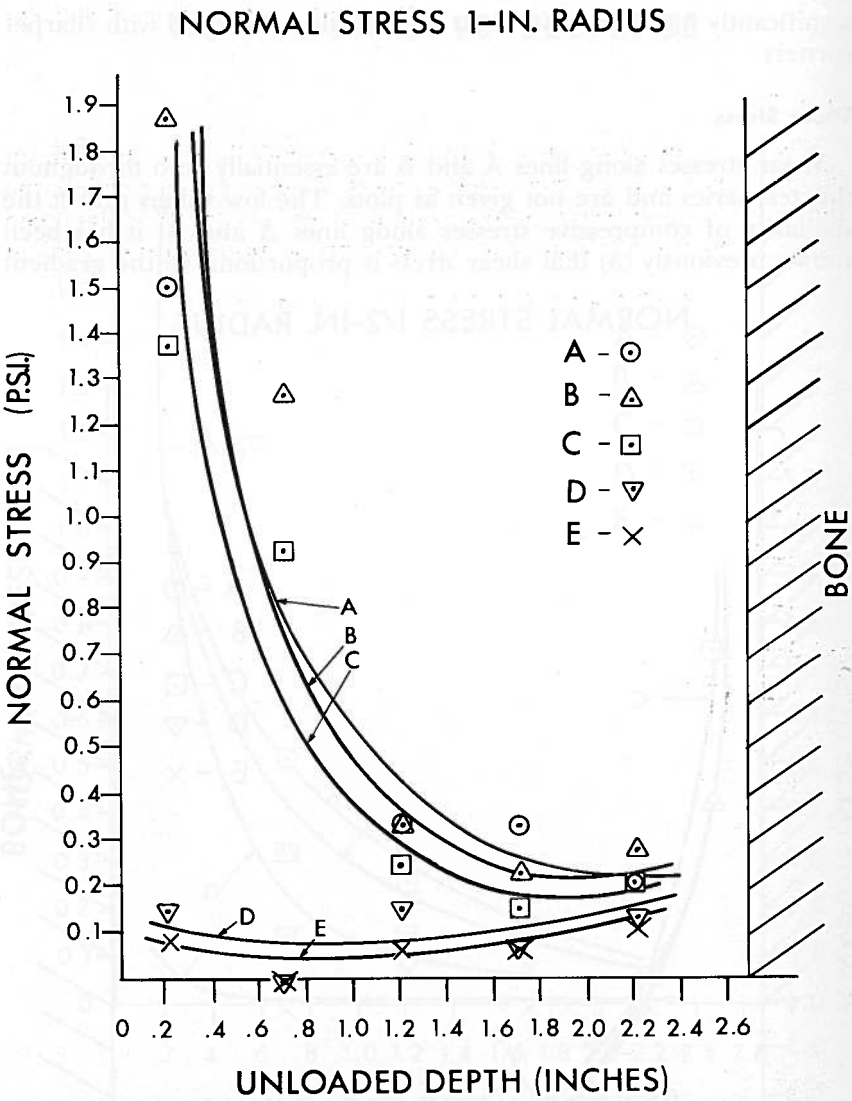

FIGURE 7.—Compressive stress resulting from 1-in.-radius test shown in Figure 4.

of compressive stress, i.e., the slope with respect to the horizontal axis, in Figures 5, 6, and 7, which in this case approaches zero. Line C, while sharing essentially identical compressive stress values with line B, usually differs sharply in compressive stress with its neighbor, line D. Therefore, significant shear usually appears at line C for it experiences at least a unilateral compressive stress gradient, i.e., a

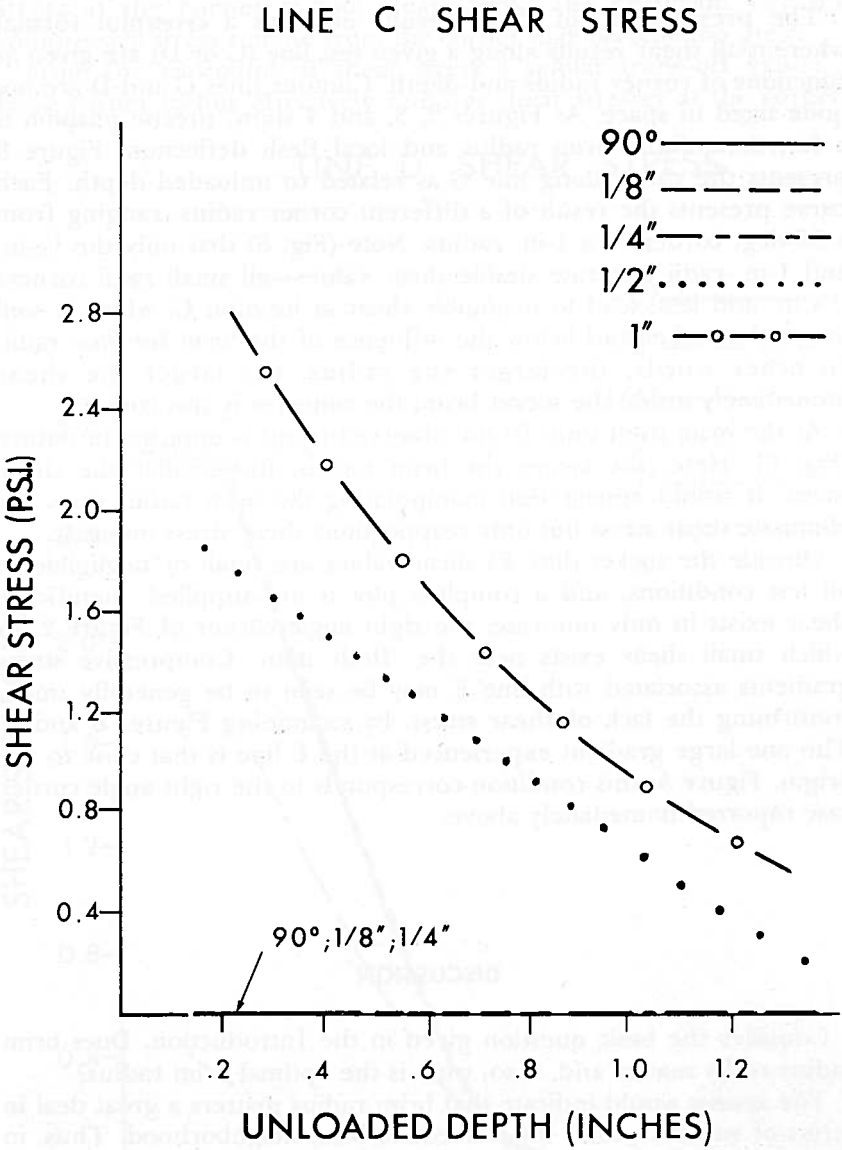

FIGURE 8.—Shear stress developed along contour line C for all tested radii.

gradient on the C to D side. Line D typically evidences a considerable compressive stress gradient, as may be seen by casually examining Figures 5, 6, and 7 along any desired "unloaded depth" line.

The presentation of shear results employs a crossplot format wherein all shear results along a given test line (C or D) are given as functions of corner radius and depth. Contour lines C and D are not quite fixed in space. As Figures 2, 3, and 4 show, precise position is a function of the brim radius and local flesh deflection. Figure 8 presents the shear along line C as related to unloaded depth. Each curve presents the result of a different corner radius, ranging from a 90-deg. corner to a 1-in. radius. Note (Fig. 8) that only the 1/2-in. and 1-in. radii generate sizable shear values—all small radii corners (1/4 in. and less) lead to negligible shear at location C, which is well inside the socket and below the influence of the brim for *these* radii. In other words, the larger the radius, the larger the shear immediately inside the socket brim; the converse is also true.

At the brim itself (line D) the observed trend is opposite in nature (Fig. 9). Here, the larger the brim radius, the smaller the shear stress. It would appear that manipulating the brim radius does not eliminate shear stress but only reapportions shear stress intensity.

Outside the socket (line E) shear values are small or negligible in all test conditions, and a complete plot is not supplied. Significant shear exists in only one case, the right angle corner of Figure 2, in which small shear exists near the "flesh skin." Compressive stress gradients associated with line E may be seen to be generally small, confirming the lack of shear stress, by examining Figures 6 and 7. The one large gradient experienced at the E line is that close to the origin, Figure 5; this condition corresponds to the right angle corner case reported immediately above.

DISCUSSION

Consider the basic question given in the Introduction. Does brim radius really matter and, if so, what is the optimal brim radius?

The results would indicate that brim radius matters a great deal in terms of stresses within the immediate brim neighborhood. Thus, in switching from a sharp corner to a 1-in.-radius brim, the local flesh compressive stresses are reduced by a factor of five. However, the beneficial aspect of large radii is subject to diminishing returns; the difference in performance between a 1/2-in. radius and a 1-in. radius is less impressive (about 50 percent).

Away from the corner itself, the act of employing large radii tends to increase the compressive stress levels. Thus, some optimum radius would seem to exist; beneath the optimum size the compressive

stress at the corner is too great, above the optimum size the compressive stress remote from the corner may become too great.

From the viewpoint of shear stress a similar trade-off exists; a large corner radius effectively removes shear stresses at the corner,

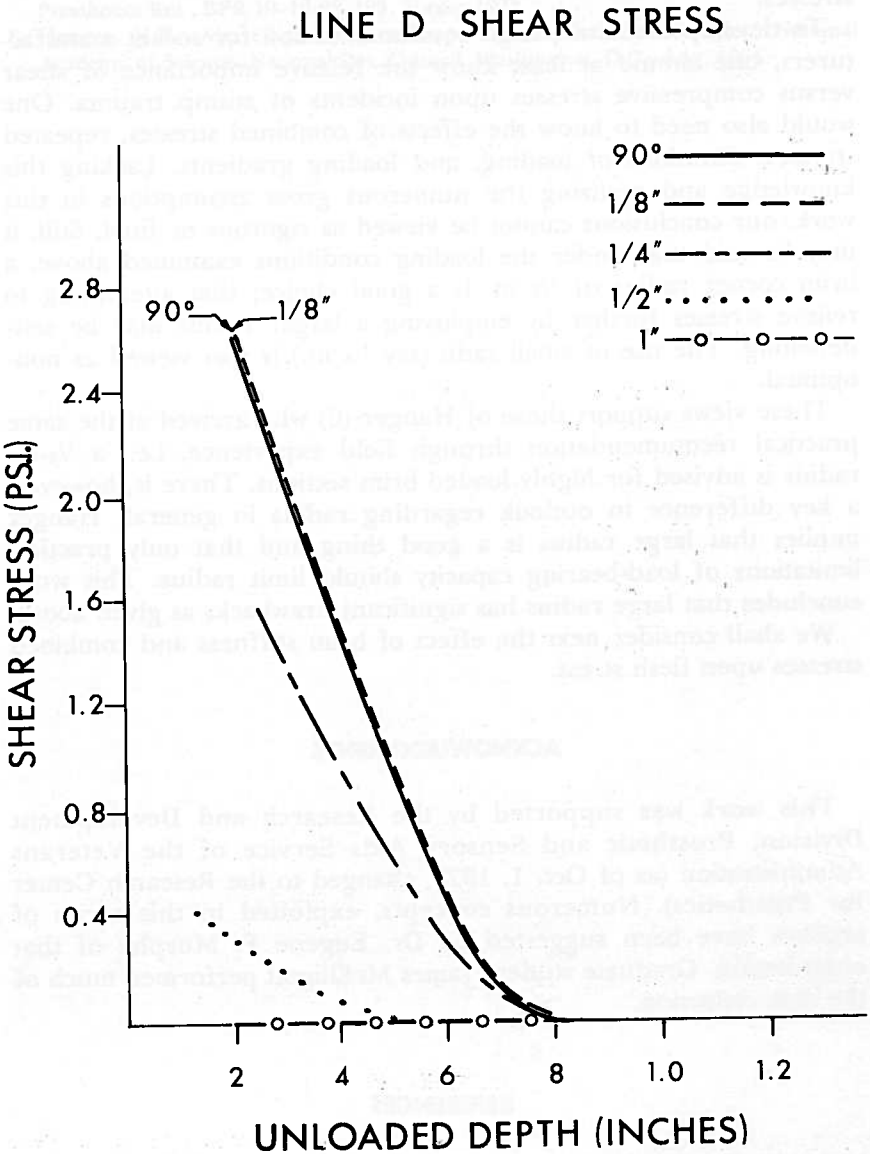

FIGURE 9.—Shear stress developed along contour line D for all tested radii.

but does so only at the price of transferring the undesired stresses to a point immediately inside the corner. A medium radius (about 1/2 in.), offering medium stresses at both corner and inside locations, would appear optimal from the standpoint of distributing shear stresses.

To develop a sound design recommendation for socket manufacturers, one should at least know the relative importance of shear versus compressive stresses upon incidents of stump trauma. One would also need to know the effects of combined stresses, repeated stresses, durations of loading, and loading gradients. Lacking this knowledge and realizing the numerous gross assumptions in this work, our conclusions cannot be viewed as rigorous or final. Still, it may be said that under the loading conditions examined above, a brim corner radius of 1/2 in. is a good choice; that attempting to relieve stresses further by employing a larger radius may be self-defeating. The use of small radii (say 1/8 in.) is also viewed as non-optimal.

These views support those of Hanger (6) who arrived at the same practical recommendation through field experience, i.e., a 1/2-in. radius is advised for highly loaded brim sections. There is, however, a key difference in outlook regarding radius in general; Hanger implies that large radius is a good thing and that only practical limitations of load-bearing capacity should limit radius. This work concludes that large radius has significant drawbacks as given above.

We shall consider next the effect of brim stiffness and combined stresses upon flesh stress.

ACKNOWLEDGMENTS

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