EFFECTIVE AREA OF A BOLTED CONNECTION

by

G. C. SRIVASTAVA

B. E. (Hons.), Government Engineering College
Jabalpur, India, 1955

_____

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1964

Approved by:

_____
Major Professor

TABLE OF CONTENTS

# INTRODUCTION

Proper design of bolted assemblies requires a comprehensive knowledge of the behaviour of the bolt and bolted members under a particular type of loading. Enough information is available as regards the bolt, but little is known about the connected parts. Valuable data needed in the design are "How the strains vary in such joints?" and "What is the 'effective area' of the bolted members on which the bolt load can be assumed to act uniformly?" With this knowledge it will be possible to avoid the failure of bolts and bolted joints, which have posed a serious problem in present-day designs.

For calculating the "effective area" of the bolted members, many approaches with different assumptions have been made. The result obtained in each case differed considerably from each other. This created a confusion as to which result should be accepted for design.

In an attempt to answer this question, an experimental investigation was carried out and the findings are presented in this report.

## PREVIOUS WORK ON THE 'EFFECTIVE AREA' OF A BOLTED CONNECTION

S. Bathwal [1]* compared five different approaches for determining the effective areas of bolted parts; (1) the whole

---

*Refer to bibliography.

area of the flange, (2) using the average deflection of a beam
on an elastic foundation, (3) using a root-mean-square value
of deflection of a beam on an elastic foundation, (4) by strain
energy method, and (5) by using Radzimvosky's equation for
infinite plates. He analyzed a flanged joint that had been
studied by Robert [2]. The flange in question was of steel
1/4" thick and 1" wide with bolts spaced 24" apart.

A unit load at the bolt locations was assumed and the
effective areas calculated according to the five approaches.
Areas of 24 sq. in., 3.52 (10)$^{16}$ sq. in., 4.45 sq. in.,
1.12 sq. in. and 0.049 sq. in. respectively, were obtained. No
two results were within reasonable agreement. This report pre-
sents the findings of an experimental investigation of a bolted
joint.

## EXPERIMENTAL INVESTIGATION

To determine the effective area of bolted parts, it is
necessary to know the stress-distribution-pattern and the
stress-magnitude at various points. The easiest way to deter-
mine stress is by measuring the strains. Therefore strains, at
various locations in a flanged-joint, were measured as described
below.

Two aluminum plates of 5" diameter and 1" thick, were used
as test-pieces. Their surfaces were made perfectly level and
smooth. A hole of 1" diameter was drilled in the center. Small
holes, 1/4" in diameter, were drilled at various distances from

the center, as shown in Fig. 1, for the mounting of strain gages.

Instead of a bolt and nut, two steel studs, Fig. 1, were used to clamp the test-pieces. The stem-diameter of the studs was equal to that of the bolt-shank and the head-diameter of the stud equalled the diameter of the bolt head washer-face. The load was applied by means of a compression testing machine, Fig. 2. This had the same effect on the plates as a bolt and provided an accurate control of the load applied.

Strain gages were cemented on the inner side of the holes (the side nearest to the center of the plate) and as close to the contact-surfaces as possible. Appendix 3 gives the details of the cementing procedure. The leads of each strain gage, were connected to the switching and balancing unit of the S-R strain recording equipment, Fig. 2. Loads of 4,000 lbs. to 16,000 lbs. were applied, in increments of 2,000 lbs. The strain at each location, was recorded for the different loads.

The first test-run was conducted without a gasket. In the second experiment, a gasket of 1/8" thickness was inserted between the plates. The experiment is described in detail in Appendix 3.

The locations of the ten strain gages are tabulated on page 6.

The data, tabulated in Appendix 1, were plotted in two different ways:

> Strain vs. distance at different loads and
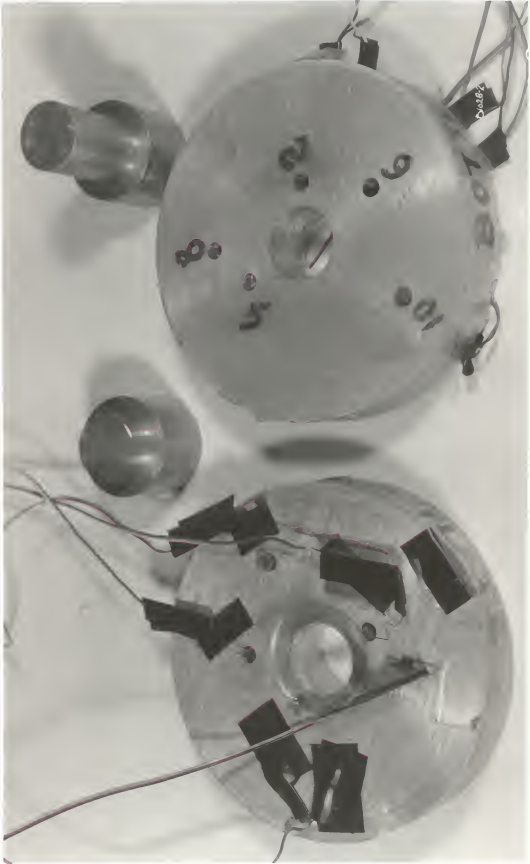> Strain vs. load at each location.

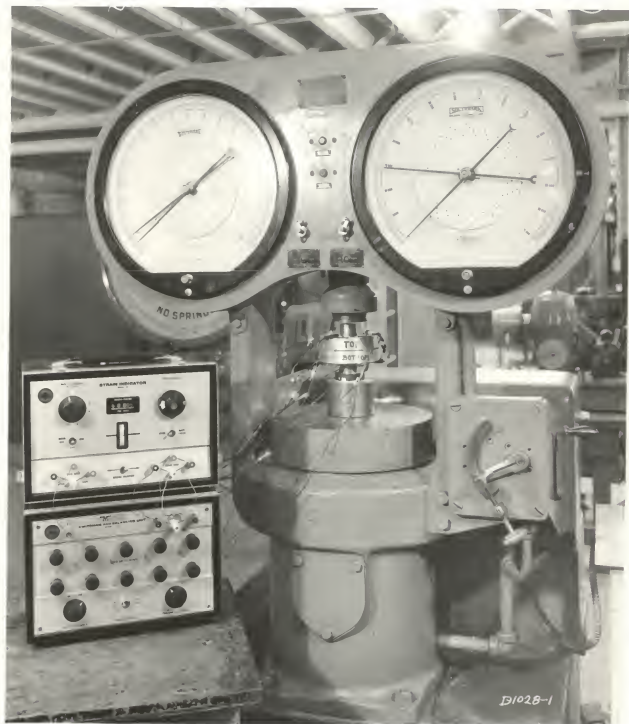Fig. 1. The two aluminum test-pieces with studs.

Fig. 2.  The test set up.

| Strain gage location | : : : | Distance from center line of plates in inches |
|:---:|:---:|:---:|
| No. 1 | | .500 |
| No. 2 | | .575 |
| No. 3 | | .775 |
| No. 4 | | .975 |
| No. 5 | | 1.175 |
| No. 6 | | 1.375 |
| No. 7 | | 1.575 |
| No. 8 | | 1.775 |
| No. 9 | | 1.975 |
| No. 10 | | 2.175 |

## DISCUSSION

The plot of strains vs. distance shows that the compressive strains decreased as the distance from the center of the plate increased. The decline in compressive strains was quite rapid near the center, becoming more gradual with increase in distance. At a distance of 1.975", the strains became insignificant. This indicates that the effective area of the bolted connection is not greater than a circular area of diameter equal to 3.95". It is further observed that at larger loads, the decrease of compressive strains with radial distance is more rapid than that at lower loads.

The graph of strain vs. load indicates that the strain bears a linear relation to the load. For larger loads these

Strain vs. Distance for Various Loads

Bolted Connection
Two Aluminum Discs, No Gasket

(Loads in lbs.)

Curve A —  4,000
  " B —  6,000
  " C —  8,000
  " D — 10,000
  " E — 12,000
  " F — 14,000
  " G — 16,000
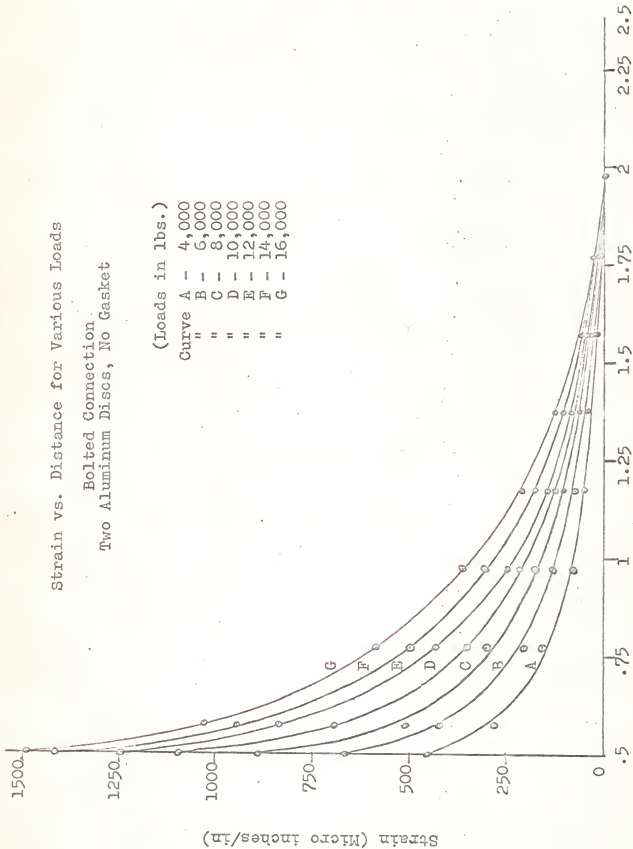
Distance from center (inches).

Fig. 3. Strain vs. distance.

Strain (Micro inches/in)

Strain vs. Load for Various Locations
Bolted Connection
Two Aluminum Discs, No Gasket

Fig. 4. Strain vs. load.

8

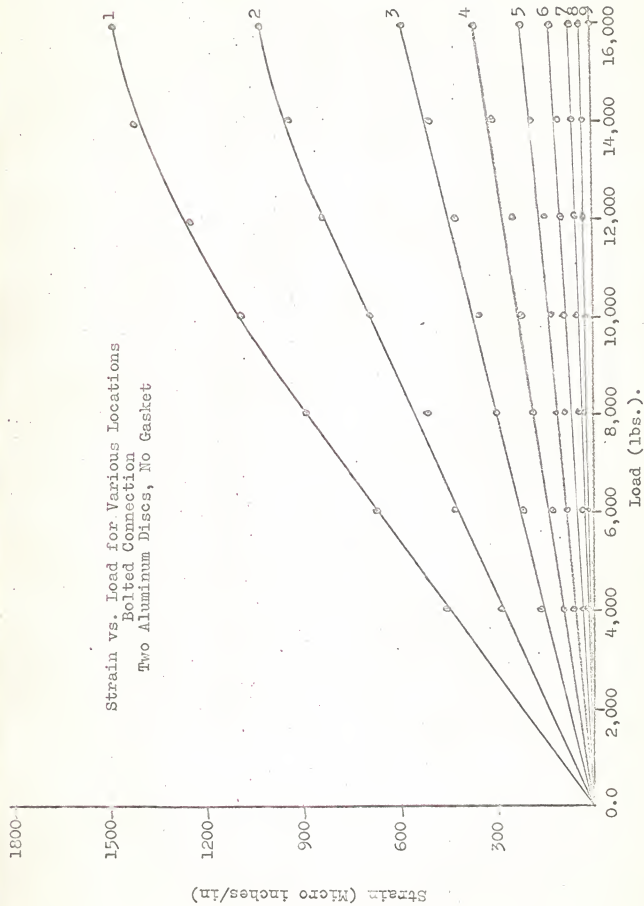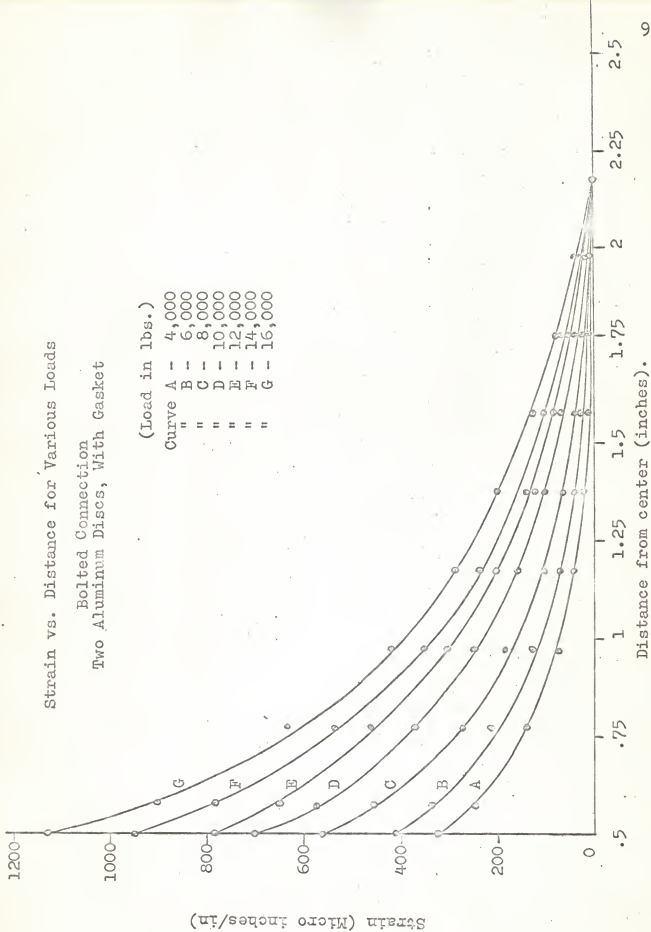Strain vs. Distance for Various Loads
Bolted Connection
Two Aluminum Discs, With Gasket

(Load in lbs.)

Curve A — 4,000
" B — 6,000
" C — 8,000
" D — 10,000
" E — 12,000
" F — 14,000
" G — 16,000

Distance from center (inches).
Fig. 5.  Strain vs. distance.

Strain (Micro inches/in)

Strain vs. Load for Various Locations
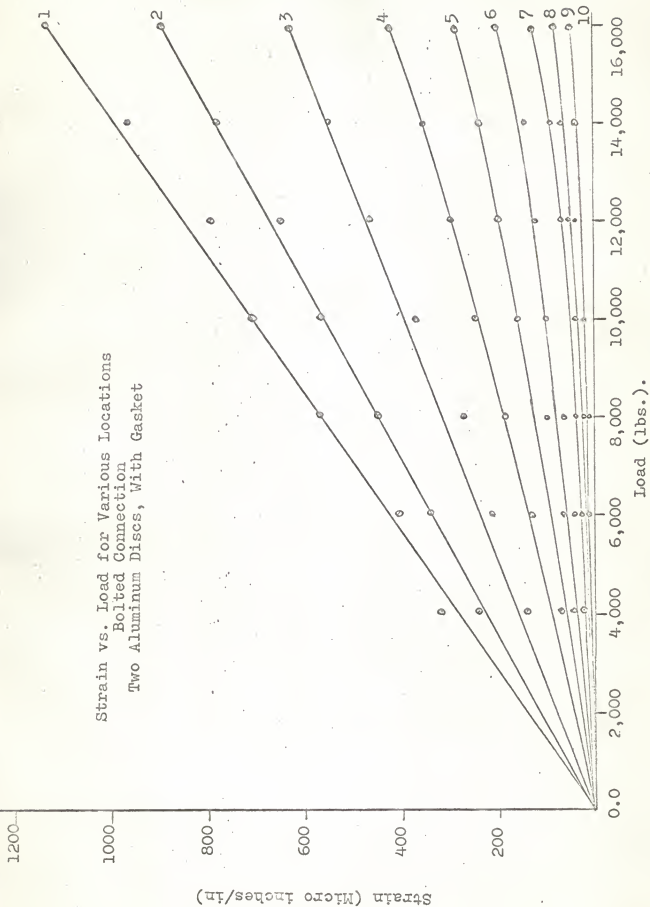Bolted Connection
Two Aluminum Discs, With Gasket

Fig. 6. Strain vs. load.

lines are much farther apart than for smaller loads.

In the bolted connection using a gasket, the plot of strains against distance shows that the strains are distributed over a larger area and the maximum strains are also reduced. The strains, thus, are distributed more uniformly. The general nature of the graphs, remains the same, though changes are less rapid.

No strain was measured at Location 10, indicating that the effective area of the bolted connection with a gasket, is not greater than a circular area of diameter equal to 4.4".

## EFFECTIVE AREA

Many effective areas were obtained using the experimentally determined strains. They were based on:

(1) Maximum strain.

(2) Mean effective strain.

(3) Energy stored in the plates due to compression assuming linear relationship between the load and the deformation.

(4) Actual energy stored in the plates as obtained by load-deformation curves.

Two values for each case were calculated; one without gasket, the other with a gasket and are tabulated below. For detailed calculations see Appendix 2.

Effective area and equivalent diameter

| Method | Without gasket | | With gasket | |
|:------:|:----------------:|:--------------------:|:-----------------:|:---------------------:|
|        | Area in sq. in. | Diameter in inches | Area in sq. in. | Diameter in inches |
| 1 | 0.91 | 1.47 | 1.18 | 1.58 |
| 2 | 11.8 | 4.00 | 8.12 | 3.37 |
| 3 | 0.913 | 1.475 | 1.116 | 1.556 |
| 4 | 1.03 | 1.52 | 1.07 | 1.54 |

The effective area based on Radzimvosky's equation [3] is

$$A = \frac{\pi}{4} (D_e^2 - d^2)$$

where $D_e = D_w + \dfrac{h_1 + h_2 + h_g}{2}$

$D_w$ – diameter of the washer face of the nut.

$h_1$, $h_2$ and $h_g$ are the thicknesses of plates and the gasket.

d – diameter of the bolt shank.

For the case with no gasket, the equivalent diameter;

$$D_e = 1.5 + \frac{1 + 1}{2} = 2.5 \text{ in.}$$

The effective area; $A = 4.12$ sq. in.

For the case with a 1/8" thick gasket, the equivalent diameter;

$$D_e = 1.5 + \frac{1 + 1 + 1/8}{2} = 2.563 \text{ in.}$$

The effective area; $A = 4.4$ sq. in.

## SUMMARY AND RECOMMENDATIONS

The effective area of a bolted connection was determined experimentally in order to find which of the five approaches considered by Bathwal yields results closest to that actually found in practice.

The strains at various distances in an aluminum bolted assembly were measured by means of strain gages cemented in small holes drilled in the plates. Resemblance to a bolted joint under load was achieved by applying load on the upper stud. The strains at various loads were determined.

The effective areas were calculated by four different approaches, (1) using maximum strain, (2) using mean effective strain, (3) using energy method and assuming perfect linear relationship between load and deformation, and (4) using energy method and making use of the actual energy stored in the plates as indicated by the area under load-deformation-curve.

The effective areas obtained by the first, third and fourth approaches are quite close to each other. The effective area obtained by the fourth approach appears to be a reasonable value as it is based on the actual energy stored in the plates. Thus it can be concluded that the strain energy approach yields results that are close to those found in actual practice.

The effective areas obtained from Radzimvosky's equation are about four times that determined experimentally. The use of the larger area in the bolt-load equation

$$F_t = F_i + mF_e$$

results in decreased bolt-load.

The values of m for areas obtained experimentally and using Radzimvosky's equation are, 0.655 and 0.322, respectively.

Thus, for an external load of 16,000 lbs., the total load on bolt is 21,200 lbs. according to Radzimvosky's equation, though actually it is 26,500 lbs. as found experimentally. Therefore, a design based on Radzimvosky's equation will not be very safe.

For further work in this area, it is recommended that:

(1) The photoelastic technique may be used to determine three-dimensional stresses, which should reflect the true behaviour more accurately.

(2) Experimental investigations may be made using joints of different material and having different dimensions and shapes.

(3) Experimental investigations may also be made on the bolted connections subjected to rapidly varying loads.

(4) This experiment shows that the methods presently used to determine the effective area of bolted parts are not satisfactory.  On the basis of the results of this test, it is not possible to develop an emperical equation.

Therefore, it is recommended that further testing be undertaken with the aim of developing an emperical relation that can be used in designing bolted connections.

## ACKNOWLEDGMENT

The author wishes to express his sincere appreciation
to Dr. John C. Lindholm, major professor, for his advice and
counsel during the investigation and subsequent interpreta-
tion of the results.  Also, the author expresses his appre-
ciation to Professor Frank J. McCormick for help in develop-
ing the experimental technique of mounting the strain gages.

BIBLIOGRAPHY

1.  Bathwal, S.
        Bolted Connections.  A Master's Report, Kansas
        State University, 1963.

2.  Robert, S. I.
        Gasket and bolted joint.  A.S.M.E. Journal Applied
        Mechanics, Volume 72.  p. 169.

3.  Radzimvosky, E. I.
        Bolt design for repeated loading.  Machine Design,
        Volume 24.  November, 1952.  p. 135.

4.  Faires, V. M.
        Design of Machine element.  Third Edition,
        New York, The Macmillan Company, 1961.

5.  Kimball, D. S., and J. H. Barr.
        Element of Machine Design.  John Willey and Sons,
        Third Edition.  p. 278.

6.  S. E. S. A.
        Manual on experimental stress analysis techniques--
        1957.

7.  Budd Company, Phoenixville, Pennsylvania.
        Instruction Bulletin, Budd Metalfilm 101 Series.

8.  Baldwin-Lima-Hamilton Corporation.
        Instruction Manual for B L H Strain Indicator,
        type - 20.

APPENDICES

APPENDIX 1

Table 1. Strain (micro inches/in) vs. load for various locations
Bolted Connection
Two aluminum discs, no gasket.

| No. of Holes | Distance from center in inches | Loads in lbs. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 4,000 | 6,000 | 8,000 | 10,000 | 12,000 | 14,000 | 16,000 |
| 1 | .500 | 0 | 450 | 665 | 880 | 1,080 | 1,230 | 1,400 | 1,470 |
| 2 | .575 | 0 | 280 | 420 | 510 | 690 | 830 | 935 | 1,020 |
| 3 | .775 | 0 | 160 | 210 | 300 | 350 | 430 | 500 | 585 |
| 4 | .975 | 0 | 85 | 130 | 180 | 220 | 250 | 310 | 370 |
| 5 | 1.175 | 0 | 55 | 80 | 110 | 130 | 150 | 185 | 220 |
| 6 | 1.375 | 0 | 50 | 70 | 85 | 90 | 100 | 115 | 130 |
| 7 | 1.575 | 0 | 25 | 30 | 40 | 50 | 55 | 60 | 65 |
| 8 | 1.775 | 0 | 20 | 20 | 25 | 25 | 30 | 30 | 30 |
| 9 | 1.975 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 2.175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 2. Strain (micro inches/in) vs. load for various locations
Bolted Connection
Two aluminum discs, with gasket.

| No. of Holes | Distance from center in inches | Loads in lbs. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 4,000 | 6,000 | 8,000 | 10,000 | 12,000 | 14,000 | 16,000 |
| 1 | .500 | 0 | 320 | 400 | 565 | 700 | 780 | 950 | 1,130 |
| 2 | .575 | 0 | 240 | 335 | 450 | 565 | 640 | 770 | 885 |
| 3 | .775 | 0 | 140 | 210 | 265 | 370 | 460 | 535 | 630 |
| 4 | .975 | 0 | 70 | 125 | 185 | 250 | 300 | 350 | 415 |
| 5 | 1.175 | 0 | 40 | 65 | 100 | 160 | 200 | 235 | 285 |
| 6 | 1.375 | 0 | 20 | 35 | 65 | 100 | 120 | 135 | 200 |
| 7 | 1.575 | 0 | 10 | 25 | 30 | 40 | 70 | 85 | 125 |
| 8 | 1.775 | 0 | 10 | 20 | 20 | 35 | 50 | 70 | 75 |
| 9 | 1.975 | 0 | 0 | 10 | 20 | 25 | 40 | 45 | 45 |
| 10 | 2.175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

APPENDIX 2

The effective areas were obtained using the experimentally determined strains. The strain and area are related by the equation

$$\delta = L \epsilon = \frac{PL}{AE}$$

where $\delta$ - total deformation of parts parallel to the line of load applied.

$L$ - length of parts parallel to the line of load applied.

$\epsilon$ - strain in the line of load applied.

$P$ - load, 16,000 lbs. for 1" bolt.

$A$ - effective cross sectional area of parts.

$E$ - modulus of elasticity, $12 \times 10^6$ psi.

Solving for the area, we have

$$A = \frac{P}{\epsilon E}$$

The above equation assumes that the strain is uniform over the area. The graphs of strain vs. distance show that the strain varies continually with increasing radii. In order to use the equation, some particular magnitude of strain must be taken.

(a) Effective area using maximum strain.

Without gasket

Without gasket, the maximum strain of $1470 \times 10^{-6}$ in./in. occurred at the center hole. The effective area,

$$A = \frac{P}{\epsilon E} = \frac{16,000}{1470 \times 10^{-6} \, (12 \times 10^6)} = 0.91 \text{ sq. in.}$$

The equivalent diameter for this area, is

$$A = \frac{\pi}{4} (D_e^2 - 1)$$

or $D_e^2 = \frac{0.91}{0.7854} + 1$

or $D_e = 1.47$ in.

## With gasket

With gasket, the maximum strain of $1130 \times 10^{-6}$ in./in. occurred at the center hole. The effective area

$$A = \frac{16,000}{1130 \times 10^{-6} (12 \times 10^6)} = 1.18 \text{ sq. in.}$$

The equivalent diameter $D_e = 1.58$ in.

(b) Effective area, using mean effective strain. The mean effective strain can be determined by finding the volume of the body, generated by the strain-curve and dividing it by the area of the base.
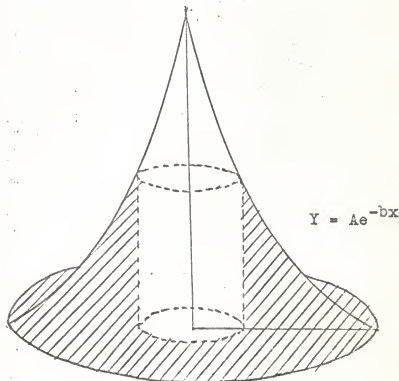


$Y = Ae^{-bx}$

Fig. 7. Body generated by strain-curve.

The strain-curve, was assumed to be of the exponential form $Y = Ae^{-bx}$ and the constant A and b were calculated using the method of least squares on the strain-data obtained for the 16,000 lb. load.

The volume of the shaded portion, (Fig. 7)

$$V = \frac{2\pi A}{b^2} \left[ e^{-\frac{b}{2}} (\frac{b}{2} + 1) - e^{-2b} (2b + 1) \right] - \frac{\pi h}{4}$$

Without gasket

$A = 5754 \times 10^{-6}$ ; $b = 2.86$

$$V = \frac{2\pi\, 5754 \times 10^{-6}}{2.86^2} \left[ 0.581 - 0.022 \right] - \frac{\pi}{4} (1470 \times 10^{-6})$$

$= 1330 \times 10^{-6}$ cu. in.

Area of the base $= \frac{\pi}{4} \left[ 2^2 - (1/2)^2 \right] = 11.8$ sq. in.

mean effective strain $= \frac{1330 \times 10^{-6}}{11.8} = 112.8 \times 10^{-6}$ in./in.

The effective area

$$A = \frac{P}{\epsilon\, E} = \frac{16,000}{(112.8 \times 10^{-6})(12 \times 10^6)} = 11.8 \text{ sq. in.}$$

The equivalent diameter, $D_e = 4$ in.

With gasket

The equation for the strain-curve, in this case is

$Y = (3467 \times 10^{-6})\, e^{-2.16x}$

The volume of the shaded portion,

$$V = \frac{2\pi\, (3467 \times 10^{-6})}{2.16^2} \left[ e^{-1.08}(2.08) - e^{-4.78}(5.78) \right] -$$

$$\frac{\pi \times 1130 \times 10^{-6}}{4}$$

$$= 2293 \times 10^{-6} \text{ cu. in.}$$

The base area $= \pi (2.175^2 - .5^2)$

$$= 14 \text{ sq. in.}$$

The mean effective strain $= \dfrac{2293 \times 10^{-6}}{14} = 164 \times 10^{-6} \text{ in./in.}$

The effective area $A = \dfrac{16,000}{(164 \times 10^{-6})(12 \times 10^6)} = 8.12 \text{ sq. in.}$

The equivalent diameter $De = 3.37$ in.

    (c) Effective area, using energy method assuming perfect

       linear relationship between load and deformation.

<u>Without gasket</u>

    The relation between the total load on the bolt and the external load is given by Faires [4].

$$F_t = F_i + mF_e \qquad\qquad \text{Eq. (A)}$$

where $m = \dfrac{\left(\dfrac{L}{AE}\right)_a}{\left(\dfrac{L}{AE}\right)_b + \left(\dfrac{L}{AE}\right)_a} \qquad\qquad \text{Eq. (B)}$

    Subscript a, refers to aluminum plates and b, refers to bolt.

$F_t$ - total load on the bolt.

$F_i$ - initial tightening load.

$F_e$ - external load.

At the point of opening of the connection $F_t = F_e$.

The expression for initial tightening load as given by Kimball and Barr [5] is

$$F_i = 16,000 \ D$$

    where D is the diameter of the bolt-shank.

For 1" bolt; $F_i$ = 16,000 lbs.

The relation between $F_o$ and $F_i$ is expressed by

$$\frac{F_o}{F_i} = \frac{\delta_i + \delta_c}{\delta_i}$$

where $F_o$ - external load at the point of opening of
the joint.

$\delta_i$ - initial elongation of the bolt.

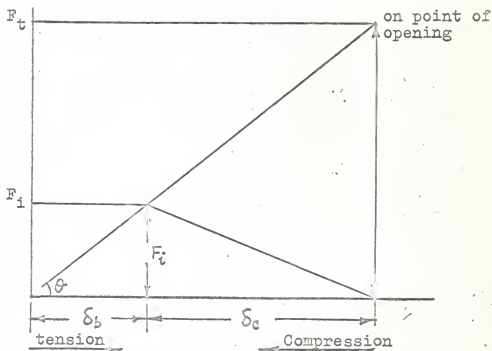$\delta_c$ - corresponding compressive deformation of
the bolted members.



Fig. 8.   Load-deformation curve for a
bolted connection.

The initial elongation of the bolt

$$\delta_i = \frac{PL}{AE} = \frac{16,000 \times 2}{.7854 \times 30 \times 10^6} = 1359 \times 10^{-6}$$

$$\delta_c = 2 \times 1470 \times 10^{-6} = 2940 \times 10^{-6}$$

$$\frac{F_o}{16,000} = \frac{(1359 + 2940)10^{-6}}{1359 \times 10^{-6}}$$

$$F_o = 50,550 \text{ lbs.} = F_e$$

Substituting the values, in equation (A)

$$50,550 = 16,000 + m(50,550)$$

or $m = 0.683$.

By substituting the following values

$$L = 2''$$
$$A_b = 0.7854 \text{ sq. in.}$$
$$E_b = 30 \times 10^6 \text{ psi.}$$
$$E_a = 12 \times 10^6 \text{ psia.}$$

In equation (B), the effective area of bolted members is

$$A = 0.913 \text{ sq. in.}$$

The equivalent diameter for this area

$$A = \frac{\pi}{4} (D_e^2 - 1)$$
$$D_e = 1.475 \text{ in.}$$

With gasket

$$\delta_i = 1359 \times 10^{-6}$$
$$\delta_a = 2260 \times 10^{-6}$$
$$\delta_g = 221 \times 10^{-4} \quad \text{(determined experimentally)}$$
$$F_o = 16,000 \left\{ \frac{\delta_i + \delta_a + \delta_g}{\delta_i} \right\}$$

$$= 16,000 \left\{\frac{0.025719}{0.001359}\right\} = 303,000 \text{ lbs.}$$

Thus the bolt load equation is

$$303,000 = 16,000 + m(303,000)$$

$$m = 0.947.$$

But

$$m = \frac{\left(\frac{L}{AE}\right)_a + \left(\frac{L}{AE}\right)_g}{\left(\frac{L}{AE}\right)_b + \left(\frac{L}{AE}\right)_a + \left(\frac{L}{AE}\right)_g} \qquad \text{Eq. (C)}$$

Where suffixes a, g, and b refer to aluminum, gasket and bolt respectively.

The modulus of elasticity E, for gasket was calculated by comparing the deformations of aluminum plates and the gasket

$$\frac{\left(\frac{PL}{AE}\right)_a}{\left(\frac{PL}{AE}\right)_g} = \frac{0.00226}{0.0221} .$$

Cancelling P and A for aluminum and gasket (as they are same for both), and substituting other values, we have

$$E_g = 76,600 \text{ psi.}$$

Substituting the values in Equation (C) we have,

$$0.947 = \frac{\dfrac{2}{A \times 12 \times 10^6} + \dfrac{1/8}{A \times 0.0766 \times 10^6}}{\dfrac{2.125}{.7854 \times 30 \times 10^6} + \dfrac{2}{A \times 12 \times 10^6} + \dfrac{1/8}{A \times 0.0766 \times 10^6}}$$

or effective area, A = 1.116 sq. in. and the equivalent diameter,

$$D_e = 1.556.$$

(d) Effective area using energy method and making use of the actual energy stored as represented in load-deformation graph.

<u>Without</u> <u>gasket</u>

The total energy in the aluminum plates under compression is given by the area under the load-deformation curve, Fig. 4.

Total energy in the two plates = 2 x area under the curve.

= 2 x (69.2)(150 x $10^{-6}$ x 1,000)

= 20.7 in lbs.

The effective area and the total energy in a plate under compression, are related by the expression.

Total energy, $U = \dfrac{P^2 L}{2AE}$

or effective area, $A = \dfrac{P^2 L}{2UE}$

$= \dfrac{16,000 \times 2}{2 \times 20.7 \times (12 \times 10^6)}$

= 1.03 sq. in.

The equivalent diameter

$D_e$ = 1.52 in.

<u>With</u> <u>gasket</u>

The total energy in the two plates and the gasket is

$$U = \left(\dfrac{P^2 L}{2AE}\right)_a + \left(\dfrac{P^2 L}{2AE}\right)_g \qquad \text{Eq. (D)}$$

and also, the total energy in the plates and the gasket is

= 1/2 P$\delta$

where $\delta = (\delta_a + \delta_g)$, the sum of deformations of the plates and the gasket.

Or     = 1/2 x 16,000 (.00226 + .0221)

= 194.88 in lbs.

Substituting these values in Eq. (D), we get

$$194.88 = \frac{(16,000)^2 \times 2}{2 \times A \times 12 \times 10^6} + \frac{(16,000)^2 \ 1/8}{2A \times 76,600}$$

or the effective area, A = 1.07 sq. in.

and the equivalent diameter, $D_e$ = 1.54 in.

APPENDIX 3

The bonded wire strain gage consists of a long fine
(.001" dia) wire sandwiched and cemented between two pieces of
thin paper.  The strain gage used in this experiment was that
of "flat grid configuration, Fig. 9.  The filament of the gage
is made of "Advance" wire and the mounting material is paper
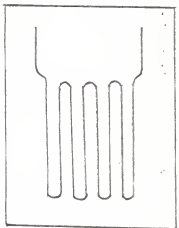impregnated with nitro-cellulose cement.



Fig. 9.  Flat grid type SR-4 bonded gage.

Lord Kelvin discovered that certain metal wires exhibited
a change of electrical resistance with change in strain.  When
the strain gage is intimately bonded to a test piece, the
strains in the surface are transmitted via the bonding agent
and paper to the fine wire grid.  As a result of this, the wire
is deformed to the same extent as the surface of the part under
test.  This deformation in wire changes its electrical resist-
ance which is measured by strain indicators.

Cementing technique

The cementing technique used was essentially that described
in the "Manual of experimental stress analysis techniques" [6]
and the "Instruction bulletin" of the Budd Company [7]. However
some details are mentioned below.

1. Surface preparation
    (1) The holes were reamed to insure smoothness.
    (2) Removed all traces of grease by degreasing it with a
        solution of trichloroethylene.
    (3) Wiped gage area with a cotton bud saturated with
        acetone.
    (4) Dried the area, before cementing the gage.

2. Soldering leads
    (1) Scraped the enamel coating of the thin insulated lead
        wires and tinned the tips.
    (2) The tips of the strain gage leads were also tinned.
    (3) Soldered the lead wires to the strain gage leads.
    (4) Put a narrow strip of scotch tape, 4" long, on the
        strain gage and the lead wire so that the gage was in
        the middle.

3. Cementing
    (1) Held the plate vertically in a vise.
    (2) Smeared a drop of the catalyst on the back side of
        the gage and dried it.
    (3) Inserted the scotch tape into the hole and held it
        tight.

(4) Put a drop of cement on the side of the hole.

(5) Pressed the scotch tape down on the cement and main-
    tained small steady pressure on the gage by means of
    thin cotton buds.

(6) Allowed two hours for drying.

Recording strains by means of strain indicator

The BHH type-20 strain gage indicator was used for meas-
uring strains.  The procedure followed was that described in
"Instruction Manual," of Baldwin-Lima-Hamilton Corporation  8 .

The wiring connections of switching and balancing unit is
similar to the wheatstone-bridge-system.  The strain gage was
connected in one arm of the bridge, the corresponding parallel
arm, contained the compensating gage.  The ten strain-gages
used, had a common compensating gage.  Each gage-circuit was
balanced before any load was applied.  For each load, each
gage-circuit was rebalanced and the strain readings recorded.

Description of the test runs

The first test run was conducted without gasket.  The test
pieces were mounted in the compression testing machine.  Leads
of the active strain gages, cemented in the 1/4" holes No. 1, 2,
3 --- 10, were connected to the "Active" terminals of the 1, 2,
3 --- 10, circuits of the switching and balancing unit.  A
common compensating gage was stuck (quite close to the edge) to
the upper plate and its leads were connected to the "Compensating

gage" terminals of the first circuit of the switching and bal-
ancing unit. The digital counter reading was adjusted to zero
by turning the R-H Knob. The pointer of "Add to Reading"
switch, was kept at 30,000. The channel selector pointer, was
placed on 1 circuit. As the indicator switch was put on, the
null-meter pointer shifted from the central mark. It was
brought to central mark by adjusting the knob of the potenti-
ometer of the first circuit. The same procedure was repeated
for each circuit. A load of 4,000 lbs. was applied to the
studs. The strain developed in the strain gage, caused the
null-meter-pointer to shift from its central position. It was
brought back to its original position by turning the digital
counter knob. The corresponding reading on "Add to Reading"
switch and digital counter, was recorded which denoted the
strain at that particular location for that load. Similarly,
the readings for other gages, were also recorded. Next, the
load was increased to 6,000 lbs. and the corresponding readings
were noted down. This practice was repeated for loads up to
16,000 lbs.

The second test-run was conducted with a 1/8" thick syn-
thetic hard rubber gasket in between the two plates. The same
procedure was followed.

EFFECTIVE AREA OF A BOLTED CONNECTION

by

G. C. SRIVASTAVA

B. E. (Hons.), Government Engineering College
Jabalpur, India, 1955

————————————————

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

A number of approaches have been made for analyzing a bolted connection. The latest approach is that given by Radzimvosky. He developed an equation assuming all the parts to be elastic, which reflects the true situation fairly well.

$$F_t = F_i + K F_e$$

$$K = \frac{\sum\limits_{i}^{n} \left(\frac{L}{AE}\right)_n \text{ parts}}{\sum\limits_{i}^{n} \left(\frac{L}{AE}\right)_n \text{ parts} + \left(\frac{L}{AE}\right)_b}$$

where $F_t$ = total load

$F_i$ = initial load

$F_e$ = external load.

In the expression for K, all terms, except area of the parts, are defined clearly. He gives the expression for the effective area of parts,

$$A = \frac{\pi}{4} (D_e^2 - d^2)$$

where $D_e = D_w + \dfrac{h_1 + h_2 + \ldots + h_n}{2}$

$D_w$ – diameter of the washer face of the bolt

d – diameter of the bolt-shank

$h_1$, $h_2$ .... $h_n$, are the thicknesses of the bolted

parts.

S. Bathwal determined the effective area of parts by five different approaches but no two results were within reasonable agreement with each other. Therefore, an experimental investigation was made to find, which of the approaches yields result

close to that actually found in practice. This report presents the findings of the investigation.

Four effective areas, were calculated on the basis of the strain-measurement. They were based on the following:

(1) Maximum strain

(2) Mean effective strain

(3) Assuming linear relation between load and the deformation of the bolted parts

(4) The actual energy stored in bolted parts during compression.

The results obtained are tabulated below.

| Method | Effective area based on experimental investigation (without gasket) in sq. in. | Effective area as calculated by Radzimvosky's equation in sq. in. |
|:---:|:---:|:---:|
| 1 | 0.91 | 4.12 |
| 2 | 11.8 | 4.12 |
| 3 | 0.913 | 4.12 |
| 4 | 1.03 | 4.12 |

Thus, it is seen that the effective area, based on Radzimvosky's equation is about four times larger than that found actually. Therefore, the use of Radzimvosky's equation tends to give a less safe design.

Similar results were obtained when a gasket was inserted between the plates.