AN EXPERIMENTAL INVESTIGATION OF STRESSES
IN A STEEL MODEL OF AN OVERLOADED BREECH RING
BY MEANS OF PHOTOELASTIC COATING TECHNIQUE

Y. F. Cheng

August 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENET WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 36KA7000204
DA Project No. 156401813GRN
PRON No. 1A0215641A1A

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.
An experimental investigation of stresses at the lower fillet in a two-dimensional steel model of an overloaded breech ring by means of photoelastic coating technique has been made. The basis of the technique is given. Expressions for stress and strain in both the elastic and elasto-plastic state are derived. Maximum fillet stress, stress concentration factor, as well as the residual stress after unloading were found. The results were compared with previous data from polycarbonate model.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>PHOTOELASTIC COATING TECHNIQUE</td>
<td>2</td>
</tr>
<tr>
<td>ANALYSIS OF STRESS AND STRAIN</td>
<td>3</td>
</tr>
<tr>
<td>EXPERIMENTS AND RESULTS</td>
<td>5</td>
</tr>
<tr>
<td>Apparatus</td>
<td>5</td>
</tr>
<tr>
<td>Materials and Calibration</td>
<td>5</td>
</tr>
<tr>
<td>Model and Loading</td>
<td>7</td>
</tr>
<tr>
<td>Maximum Fillet Stress and Stress Concentration Factor in the Elastic State</td>
<td>7</td>
</tr>
<tr>
<td>Maximum Fillet Stress and Stress Concentration Factor in the Elastoplastic State</td>
<td>9</td>
</tr>
<tr>
<td>DISCUSSIONS</td>
<td>12</td>
</tr>
<tr>
<td>Calculated Residual Stress and Percentage of Overloading</td>
<td>12</td>
</tr>
<tr>
<td>Comparison With Results Obtained Previously From Polycarbonate Model</td>
<td>12</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>17</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>19</td>
</tr>
</tbody>
</table>

## TABLES

1. **MAXIMUM STRESS, STRESS CONCENTRATION FACTOR, AND RESIDUAL STRESS AT THE LOWER FILLET**
2. **COMPARISON BETWEEN STEEL AND POLYCARBONATE MODEL**
LIST OF ILLUSTRATIONS

1. Stress-strain curve for steel. 6
2. Sketch of the model. 8
3. Curves of stress concentration factor $K$, maximum principal stress $(\sigma_1)_S$, principal strain difference $(\varepsilon_1 - \varepsilon_2)_S$, and maximum principal strain $(\varepsilon_1)_S$ versus average stress, $\sigma_{av}$. 11
4. Stress-strain curves for polycarbonate and steel. 16
ACKNOWLEDGEMENT

Charles Cobb's participation in the experimental phase of this investigation is hereby acknowledged.
INTRODUCTION

In guns with a sliding breech mechanism, breech ring failures have been observed originating from the lower fillet in the vicinity of the contact region which indicates that high tensile stress produced by stress concentration at the fillet was responsible for the failure. One can reduce the stress concentration by changing the fillet geometry or the breech ring can be overloaded into the plastic range to produce beneficial residual stress as long as future loadings are within the linearly elastic behavior of the material. Using a two dimensional polycarbonate model, the residual stress at the fillet of an overloaded breech ring after unloading has been determined by means of photoplasticity and finite element analysis.

In the two-dimensional elastic state of stress the transition of data from model to prototype requires the following conditions: equilibrium, compatibility, boundary value, and similarity of geometry and loadings. In order to make the transition involving plastic flow, at least three more conditions must be met: (a) the stress-strain curves of the materials of model and prototype must have the same shape, (b) the law of yielding must be the same for both materials, and (c) Poisson's ratio in the plastic range must be equivalent. The Poisson's ratio and the law of yielding are known

for the polycarbonate material used. Experimental data is transferable from polycarbonate model to any other material having the same value of Poisson's ratio and following the same law of yielding. The shape of the stress strain curve is represented by a parameter in the Ramberg-Osgood equation. It is possible to alter the shape of the stress-strain curve of polycarbonate material by adjusting the temperature and relative humidity of the laboratory so that the curve corresponds more closely to that of a particular prototype material.

This report describes a further study on stresses at the lower fillet in a two dimensional steel model of an overloaded breech ring by means of photoelastic coating technique. The basis of the technique is given. Expressions for stress and strain in both the elastic and elastoplastic state are derived. The steel model was loaded up to more than 100% of overloading. Maximum fillet stress, stress concentration factor, as well as the residual stress after unloading were found. The results were compared with previous data from polycarbonate model. The reliability of both photoplasticity and coating technique are ascertained.

PHOTOELASTIC COATING TECHNIQUE

The photoelastic coating technique was initially introduced by Mesnager in 1930. The method is based upon the bonding of a thin sheet of photoelastic material to the surface of a specimen. When load is applied to the specimen, strains are transmitted to the coating material which then becomes

---

birefringent. Polarized light is reflected from the surface of the specimen at normal incidence, and fringe patterns are obtained as in the photoelastic method. The photoelastic coating material in effect acts as a strain gage and permits the determination of the strains of the specimen over the coated area.

The fringe pattern is related to the principal strain difference, \((\varepsilon_1-\varepsilon_2)_s\), on the surface of the specimen by the following equation

\[ N = 2C't(\varepsilon_1-\varepsilon_2)_s \]  

(1)

and

\[ (\varepsilon_1-\varepsilon_2)_s = (\varepsilon_1-\varepsilon_2)_p \]  

(2)

where \(N\) denotes the fringe order, \(C'\) a strain-fringe constant, \(t\) thickness of the coating layer, and subscripts \(s\) and \(p\) refer to the specimen and coating, respectively.

The fringe pattern, therefore, directly gives the distribution of the principal strain difference on the surface of the specimen. Total strain difference, the sum of the elastic and plastic parts, are measured.

ANALYSIS OF STRESS AND STRAIN

On the surface of the specimen and the coating material, stress-strain relations are governed by Hooke's law as follows

\[ (\varepsilon_1-\varepsilon_2)_s = (1+\mu_s)(\sigma_1-\sigma_2)_s/E_s \]  

(3)

\[ (\varepsilon_1-\varepsilon_2)_p = (1+\mu_p)(\sigma_1-\sigma_2)_p/E_p \]  

(4)

where \(\mu\) denotes Poisson's ratio, \(E\) Young's modulus, and \(\sigma_1\) and \(\sigma_2\) the principal stresses.
In the coating material, the fringe \( N \) is directly proportional to the principal stress difference \((\sigma_1 - \sigma_2)_p\) by the following equation

\[
N = 2Ct(\sigma_1 - \sigma_2)_p
\]

where \( C \) is the stress-fringe constant and

\[
C = (1 + \mu_p)(c'/E_p)
\]

Combining equations (1) to (6), we have

\[
(\sigma_1 - \sigma_2)_s = (N/2C't)[E_s/(1 + \mu_s)]
\]

\[
= (N/2C't)(E_s/E_p)[(1 + \mu_p)/(1 + \mu_s)]
\]

On the free boundary one of the principal stresses is identically zero. In the elastic state the other principal stress can be readily calculated from equation (7).

In the plastic state we have

\[
(\varepsilon_1 - \varepsilon_2)_s = N/2C't
\]

and

\[
(\varepsilon_1 + \varepsilon_2 + \varepsilon_3)_s = 0
\]

This is not sufficient to separate individual principal strain and stress except those on the free boundary of a plane stress problem where

\[
(\sigma_2)_s = (\sigma_3)_s = 0
\]

and

\[
(\varepsilon_2)_s = (\varepsilon_3)_s = -0.5(\varepsilon_1)_s
\]

The principal strain \((\varepsilon_1)_s\) in the specimen tangent to the free boundary becomes, from equation (11)

\[
(\varepsilon_1)_s = N/3C't
\]
The principal stress \( (\sigma_1)_S \) in the specimen corresponding to the principal strain \( (\varepsilon_1)_S \) can be found from the stress-strain relation for the specimen material in uniaxial tension.

EXPERIMENTS AND RESULTS

Apparatus

A portable reflection type polariscope with monochromatic light of 5461 Å was used, and photoelastic patterns at normal incidence were recorded. Static loads were applied by means of Baldwin-Tate-Emery testing machine.

Materials and Calibration

Flat ground steel plate of 0.12 inch thickness with a chemical content of 0.85 - 0.95 C, 1.00 - 1.25 Mn, 0.20 - 0.40 Si, 0.40 - 0.60 Cr, 0.40 - 0.60 W, and 0.10 - 0.20 V was used as the model material. It was supplied by Simons Saw and Steel, Fitchburg, MA (Division Wallace-Murray Corp.).

Type PS-1 photoelastic sheet of 0.04 inch thickness was used as the coating material. It was supplied by Measurement Group, Raleigh, NC.

Uniaxial tension calibration specimens of steel having a cross section of 0.19 x 0.12 inch were prepared with electric resistance wire strain gages (EA-13-015DJ-120, Micromeasurement) bonded to each specimen at its midsection, one on each side. Coating material was applied on the specimen surface.

Figure 1 shows the stress-strain curve for steel from strain gage readings. It has a Young's modulus of 30 x \( 10^6 \) psi, a proportional limit of 51 x \( 10^3 \) psi and a yielding stress \( \sigma_y \), defined by the point of intersection
Fig. 1. Stress-Strain Curve for Steel
of secant modulus ($E_{\text{sec}} = 0.7E$) and the stress-strain curve, of approximately $60 \times 10^3$ psi. Poisson's ratio was taken to be 0.3.

The coating material registered one fringe every $1890 \times 10^{-6}$ in/in of axial strain. In uniaxial tension

$$\varepsilon_2 = -\mu \varepsilon_1 = -0.3 \varepsilon_1$$

(12)

and

$$\varepsilon_2 = -570 \times 10^{-6} \text{ in/in}$$

From equation (1)

$$1/(2C't) = (\varepsilon_1 - \varepsilon_2) = 2460 \times 10^{-6} \text{ in/in}$$

(13)

**Model and Loading**

Due to the available size of the model material, a 55/65 scale, two-dimensional model of the meridian section of a breech ring and block was made of 0.12 inch thick steel plate, as shown in Figure 2. In order to minimize any effect of material homogeneity, the ring was cut closely to the calibration specimens and its line of loading was parallel with that of the calibration specimens. Photoelastic coating material was bonded to both surfaces of the lower part of the ring. The boundary of the coating layer was carefully machined so as to coincide with the fillet. The model was mounted in the testing machine and the load was applied through pins at the top of the block and the ring.

**Maximum Fillet Stress and Stress Concentration Factor in the Elastic State**

The load per half-fringe order at the fillet boundary in the elastic state was found to be 2100 pounds tension, which corresponds to a principal strain difference of $(\varepsilon_1 - \varepsilon_2) = 1230 \times 10^{-6}$ in/in.
The maximum fillet stress, i.e., the maximum principal stress \((\sigma_1)_s\), tangent to the fillet boundary can be calculated from equations (7) and (13), taking into consideration of \((\sigma_2)_s = 0\). Thus

\[
(\sigma_1)_s = \frac{(N/2C't)E_s}{(1+\mu_s)}
\]

\[
= (0.5)(2460)(30 \times 10^6)/1.3
\]

\[
= 28.4 \times 10^3 \text{ psi}
\]

Alternately, it can also be obtained by means of Hooke's law. Thus, at the free boundary

\[
(\epsilon_2)_s = -(\mu\epsilon_1)_s = -0.3(\epsilon_1)_s
\]

and

\[
1.3(\epsilon_1)_s = 1230 \times 10^{-6} \text{ in/in}
\]

\[
(\sigma_1)_s = (E\epsilon_1)_s = (30)(1230)/1.3 = 28.4 \times 10^3 \text{ psi}
\]

The average stress \(\sigma_{av}\) at the cross section has a value of

\[
\sigma_{av} = 2100/[(0.12)(5.75)(55/65)] = 3.60 \times 10^3 \text{ psi}
\]

The stress concentration factor \(K\), defined as the ratio between the maximum principal stress \((\sigma_1)_s\) and the average stress \(\sigma_{av}\), is

\[
K = (\sigma_1)_s/\sigma_{av} = 7.88
\]

Maximum Fillet Stress and Stress Concentration Factor in the Elastoplastic State

After the elastic solution was obtained, the load was raised and the specimen was brought into the elastoplastic state. The load corresponding to each increasing integral fringe order was recorded. Principal strain difference \((\epsilon_1-\epsilon_2)_s\) and maximum principal strain \((\epsilon_1)_s\) were calculated from equations (1), (11), and (14), considering both elastic and plastic parts.
The proportional limit stress of the specimen material has a value of 51 x 10^3 psi. The corresponding strain is

\[(\epsilon_1)_s = (51 \times 10^3)/(30 \times 10^6) = 1700 \times 10^{-6} \text{ in/in}\]

From equation (14), \((\epsilon_2)_s = -0.3(\epsilon_1)_s\) and the elastic part of the principal strain difference is

\[\left(\epsilon_1 - \epsilon_2\right)_s = 1.3(\epsilon_1)_s = 2200 \times 10^{-6} \text{ in/in}\]

The plastic part of \((\epsilon_1)_s\) was calculated by applying equations (1) and (11) to the plastic part of principal strain difference. For example, at P = 6000 pounds, \((\epsilon_1 - \epsilon_2)_s = 4920 \times 10^{-6} \text{ in/in}\) with an elastic part of 2200 x 10^{-6} in/in and a plastic part of 2720 x 10^{-6} in/in.

\[\left(\epsilon_1\right)_s,\text{plastic} = \frac{2}{3}(2720) = 1810 \times 10^{-6} \text{ in/in}\]

and

\[\left(\epsilon_1\right)_s,\text{total} = \left(\epsilon_1\right)_s,\text{elastic} + \left(\epsilon_1\right)_s,\text{plastic}\]
\[= 1700 \times 10^{-6} + 1810 \times 10^{-6}\]
\[= 3510 \times 10^{-6} \text{ in/in}\]

The corresponding principal stress \((\sigma_1)_s\) was read from stress-strain curve, Figure 1. Average stress \(\sigma_{av}\) and stress concentration factor \(K\) were calculated. They are shown in Table I.

The results show that as long as the specimen is in the elastic state, stress concentration factor \(K\) is constant and the curve \(K\) versus \(\sigma_{av}\) is straight and horizontal. However, if \(\sigma_{av}\) is increased so that local yielding sets in at the point of highest stress, the stress concentration factor begins to decrease rather sharply, as shown in Figure 3.
Fig. 3. Curves of Stress Concentration Factor $K$, Maximum Principal Stress $(\sigma_1)_s$, Principal Strain Difference $(\varepsilon_1 - \varepsilon_2)_s$, and Maximum Principal Strain $(\varepsilon_1)_s$ versus Average Stress, $\sigma_{av}$. 
DISCUSSIONS

Calculated Residual Stress and Percentage of Overloading

The usual assumption that unloading is inherently an elastic process is made for the purpose of calculating the residual stress after unloading. For example, in the elastic state, a load of 2100 pounds produces a fillet stress of $28.4 \times 10^3$ psi. A load of 8000 pounds would produce a fillet stress of $108.2 \times 10^3$ psi. Subtractive superposition of the value with $66.3 \times 10^3$ psi from elastoplastic state of 8000 pounds gives a residual stress of $41.9 \times 10^3$ compression, as shown in Table I.

The proportional limit load is the load which produces a fillet stress equal to the proportional limit of the material. It is used as the basis for calculating the percentage of overloading. It can be shown the proportional limit load for the specimen has a value of 3770 pounds. The percentage of overloading is defined as $\frac{P-3770}{3770} \times 100\%$.

The residual stress and percentage of overloading for five loads in the elastoplastic state were calculated and shown in Table I.

Comparison With Results Obtained Previously From Polycarbonate Model

A comparison was also made between results obtained from steel and those from polycarbonate material, Table II.

In the elastic state, stress concentration factors obtained from steel has a value of 7.88 and polycarbonate material has a value of 7.67. The difference is within the range of experimental error.
TABLE I. MAXIMUM STRESS, STRESS CONCENTRATION FACTOR, AND RESIDUAL STRESS AT THE LOWER FILLET

<table>
<thead>
<tr>
<th>Load Pounds</th>
<th>Fringe Order N</th>
<th>Principal Strain Difference $(\varepsilon_1 - \varepsilon_2)_s$ in/in</th>
<th>Maximum Principal Strain $(\varepsilon_1)_s$ in/in</th>
<th>Maximum Principal Stress $(\sigma_1)_s$ psi</th>
<th>Average Stress $\sigma_{av}$ psi</th>
<th>Stress Concentration Factor $K = (\sigma_1)<em>s / \sigma</em>{av}$</th>
<th>Percentage of Overloading $(P-3770)/3770$</th>
<th>Residual Stress psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>2100</td>
<td>0.5</td>
<td>$1230 \times 10^{-6}$</td>
<td>$950 \times 10^{-6}$</td>
<td>$28.4 \times 10^3$</td>
<td>$3.60 \times 10^3$</td>
<td>$7.88$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4100</td>
<td>1</td>
<td>$2460 \times 10^{-6}$</td>
<td>$1870 \times 10^{-6}$</td>
<td>$54.9 \times 10^3$</td>
<td>$7.02 \times 10^3$</td>
<td>$7.63$</td>
<td>9</td>
<td>$-0.5 \times 10^3$</td>
</tr>
<tr>
<td>6000</td>
<td>2</td>
<td>$4920 \times 10^{-6}$</td>
<td>$3510 \times 10^{-6}$</td>
<td>$61.2 \times 10^3$</td>
<td>$10.3 \times 10^3$</td>
<td>$5.96$</td>
<td>59</td>
<td>$-19.9 \times 10^3$</td>
</tr>
<tr>
<td>7000</td>
<td>3</td>
<td>$7380 \times 10^{-6}$</td>
<td>$5150 \times 10^{-6}$</td>
<td>$63.1 \times 10^3$</td>
<td>$12.0 \times 10^3$</td>
<td>$5.26$</td>
<td>86</td>
<td>$-31.6 \times 10^3$</td>
</tr>
<tr>
<td>7600</td>
<td>4</td>
<td>$9840 \times 10^{-6}$</td>
<td>$6790 \times 10^{-6}$</td>
<td>$64.7 \times 10^3$</td>
<td>$13.0 \times 10^3$</td>
<td>$4.97$</td>
<td>102</td>
<td>$-38.1 \times 10^3$</td>
</tr>
<tr>
<td>8000</td>
<td>5</td>
<td>$12300 \times 10^{-6}$</td>
<td>$8440 \times 10^{-6}$</td>
<td>$66.3 \times 10^3$</td>
<td>$13.7 \times 10^3$</td>
<td>$4.84$</td>
<td>112</td>
<td>$-41.9 \times 10^3$</td>
</tr>
</tbody>
</table>
TABLE II. COMPARISON BETWEEN STEEL AND POLYCARBONATE MODEL

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Polycarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>2100 pounds</td>
<td>27 pounds</td>
</tr>
<tr>
<td>Maximum Fillet Stress</td>
<td>$28.4 \times 10^3$ psi</td>
<td>300 psi</td>
</tr>
<tr>
<td>Average Stress</td>
<td>$3.6 \times 10^3$ psi</td>
<td>39 psi</td>
</tr>
<tr>
<td>Stress Concentration Factor</td>
<td>7.88</td>
<td>7.67</td>
</tr>
<tr>
<td>Load</td>
<td>7600 pounds</td>
<td>1144 pounds</td>
</tr>
<tr>
<td>Maximum Fillet Stress</td>
<td>$64.7 \times 10^3$ psi</td>
<td>$9.3 \times 10^3$ psi</td>
</tr>
<tr>
<td>Percentage of Overloading</td>
<td>102</td>
<td>105</td>
</tr>
<tr>
<td>Average Stress</td>
<td>$13.0 \times 10^3$ psi</td>
<td>$1.66 \times 10^3$ psi</td>
</tr>
<tr>
<td>Stress Concentration Factor</td>
<td>4.97</td>
<td>5.61</td>
</tr>
</tbody>
</table>
In the elastoplastic state, stress concentration factor obtained from steel with 102% overloading has a value of 4.97 and that from polycarbonate material with 105% overloading has a value of 5.61.

Figure 4 shows stress-strain curves of steel and polycarbonate. The fact that polycarbonate has a higher strain-hardening effect explains its high value of stress concentration factor in the elastoplastic state, although the slight difference in percentage of overloading may affect it also.

A transition formula for stresses in the elastic state was given in the previous work. It has the following form

\[
\frac{\sigma_s}{\sigma_m} = \frac{P_s}{P_m} \left( \frac{L_m}{L_s} \right)^2
\]

where \( L \) is the characteristic length and subscripts \( s \) and \( m \) refer to specimen and model respectively. Using this equation, under a load of 2100 pounds, the steel specimen should experience a maximum fillet stress of 

\[
(2100/27)(65/55)(300) = 27.6 \times 10^3 \text{ psi}
\]

in comparison with the experimental value of 28.4 \( \times 10^3 \) psi. The difference is again within the range of experimental error.

In the elastoplastic state, the same equation gives the steel specimen, under a load of 7600 pounds and 102% overloading a maximum fillet stress of 

\[
(7600/1144)(65/55)(9300) = 73 \times 10^3 \text{ psi}
\]

in comparison with the experimental value of 64.7 \( \times 10^3 \) psi. The difference can be explained by the difference in stress-strain behavior of these materials and possibly their laws of yielding, or the difference in percentage of overloading.
CONCLUSIONS

An experimental investigation of stresses in a steel model of the meridian section of a breech ring has been made by means of photoelastic coating technique.

In the elastic state, steel model has a stress concentration factor of 7.88 in comparison with 7.67 from a polycarbonate model. Also, steel model shows a maximum fillet stress of $28.4 \times 10^3$ psi from a load of 2100 pounds in comparison with $27.6 \times 10^3$ using the transition formula and data from polycarbonate model. A good agreement is established.

As stated earlier, the transition of data in the elastoplastic state requires at least three additional conditions: (a) same value of Poisson's ratio, (b) same law of yielding, and (c) same shape of stress-strain curve. Figure 4 clearly shows the violation of the last condition. Specifically, the stress-strain curves of steel and polycarbonate at room temperature do not have the same shape, although it is possible to match them closely by adjusting the temperature and relative humidity of the laboratory. Unfortunately, facilities at this laboratory do not provide for this kind of adjustment. Nevertheless, steel model with 102% overloading shows a stress concentration factor of 4.97 in comparison with 5.61 from the polycarbonate model with 105% overloading. The difference is reasonable.

The reliability of photoelastic coating technique and photoplasticity analysis have thus been confirmed in this experiment.
Now that two methods are available in studying stresses and strains in structures after yielding. One is the photoelastoplastic stress analysis provided that the laboratory is equipped with temperature and humidity controls such that the conditions for data transition from model to prototype can be met. This can not be realized, at present, due to the considerable expenses in refitting the laboratory. The alternate method is the photoelastic coating technique, described in this report, which reveals directly the stresses and strains existing on the surface of the structure.

The gun steel (typical 4330) has a considerably higher proportional limit stress in comparison with the steel used in this investigation. For the purpose of thorough understanding the stresses and strains in an overloaded breech ring, it is proposed for future work to repeat this investigation in a 4330 steel model. The results could further provide not only another evidence of the reliability of photoelastoplastic stress analysis but also the validity of data transition formula.
REFERENCES


<table>
<thead>
<tr>
<th>Role</th>
<th>Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commander</td>
<td>1</td>
</tr>
<tr>
<td>Chief, Development Engineering Branch</td>
<td>1</td>
</tr>
<tr>
<td>Chief, Engineering Support Branch</td>
<td>1</td>
</tr>
<tr>
<td>Chief, Research Branch</td>
<td>2</td>
</tr>
<tr>
<td>Chief, LWC Mortar Sys. Ofc.</td>
<td>1</td>
</tr>
<tr>
<td>Chief, Imp. 81mm Mortar Ofc.</td>
<td>1</td>
</tr>
<tr>
<td>Technical Library</td>
<td>5</td>
</tr>
<tr>
<td>Technical Publications &amp; Editing Unit</td>
<td>2</td>
</tr>
<tr>
<td>Director, Operations Directorate</td>
<td>1</td>
</tr>
<tr>
<td>Director, Procurement Directorate</td>
<td>1</td>
</tr>
<tr>
<td>Director, Produce Assurance Directorate</td>
<td>1</td>
</tr>
</tbody>
</table>

**NOTE:** PLEASE NOTIFY ASSOC. DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.
TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

ASST SEC OF THE ARMY
RESEARCH & DEVELOPMENT
ATTN: DEP FOR SCI & TECH
THE PENTAGON
WASHINGTON, D.C. 20315

COMMANDER
US ARMY MAT DEV & READ. COMD
ATTN: DRDC
5001 EISENHOWER AVE
ALEXANDRIA, VA 22333

COMMANDER
US ARMY ARRADCOM
ATTN: DRDAR-IC
- ICA (PIASTRICS TECH
  EVAL CEN)
- ICE
- ICM
- ICS
- ICM
- TSS(STINFO)
DOVER, NJ 07801

COMMANDER
US ARMY ARRADCOM
ATTN: DRDAR-LEP-L
ROCK ISLAND ARSENAL
ROCK ISLAND, IL 61299

DIRECTOR
US Army Ballistic Research Laboratory
ATTN: DRDAR-TSB-S (STINFO)
ABERDEEN PROVING GROUND, MD 21005

COMMANDER
US ARMY ELECTRONICS COMD
ATTN: TECH LIB
FT MONMOUTH, NJ 07703

COMMANDER
US ARMY MOBILITY EQUIP R&D COMD
ATTN: TECH LIB
FT BELVOIR, VA 22060

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY,
DRDAR-ICB-TL, WATERTVIET ARSENAL, WATERTVIET, N.Y. 12189, OF ANY
REQUIRED CHANGES.
<table>
<thead>
<tr>
<th>NO. OF COPIES</th>
<th>NO. OF COPIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMMANDER</td>
<td>COMMANDER</td>
</tr>
<tr>
<td>US ARMY RESEARCH OFFICE</td>
<td>DEFENSE TECHNICAL INFO CENTER</td>
</tr>
<tr>
<td>P.O. BOX 12211</td>
<td>ATTN: DTIA-TCA</td>
</tr>
<tr>
<td>RESEARCH TRIANGLE PARK, NC 27709</td>
<td>CAMERON STATION</td>
</tr>
<tr>
<td></td>
<td>ALEXANDRIA, VA 22314</td>
</tr>
<tr>
<td>COMMANDER</td>
<td>COMMANDER</td>
</tr>
<tr>
<td>US ARMY HARRY DIAMOND LAB</td>
<td>METALS &amp; CERAMICS INFO CEN</td>
</tr>
<tr>
<td>ATTN: TECH LIB</td>
<td>BATTELLE COLUMBUS LAB</td>
</tr>
<tr>
<td>2800 POWDER MILL ROAD</td>
<td>505 KING AVE</td>
</tr>
<tr>
<td>ADELPHIA, MD 20783</td>
<td>COLUMBUS, OHIO 43201</td>
</tr>
<tr>
<td>DIRECTOR</td>
<td>DIRECTOR</td>
</tr>
<tr>
<td>US ARMY INDUSTRIAL BASE ENG ACT</td>
<td>MECHANICAL PROPERTIES DATA CTR</td>
</tr>
<tr>
<td>ATTN: DRXPE-MT</td>
<td>BATTELLE COLUMBUS LAB</td>
</tr>
<tr>
<td>ROCK ISLAND, IL 61201</td>
<td>505 KING AVE</td>
</tr>
<tr>
<td></td>
<td>COLUMBUS, OHIO 43201</td>
</tr>
<tr>
<td>CHIEF, MATERIALS BRANCH</td>
<td>CHIEF, MATERIALS BRANCH</td>
</tr>
<tr>
<td>US ARMY R&amp;D GROUP, EUR</td>
<td>US ARMY R&amp;D GROUP, EUR</td>
</tr>
<tr>
<td>BOX 65, FPO N.Y. 09910</td>
<td>BOX 65, FPO N.Y. 09910</td>
</tr>
<tr>
<td>COMMANDER</td>
<td>COMMANDER</td>
</tr>
<tr>
<td>NAVAL SURFACE WEAPONS CEN</td>
<td>NAVAL SURFACE WEAPONS CEN</td>
</tr>
<tr>
<td>ATTN: CHIEF, MAT SCIENCE DIV</td>
<td>ATTN: CHIEF, MAT SCIENCE DIV</td>
</tr>
<tr>
<td>NAHIOREN, VA 22448</td>
<td>NAHIOREN, VA 22448</td>
</tr>
<tr>
<td>DIRECTOR</td>
<td>DIRECTOR</td>
</tr>
<tr>
<td>US NAVAL RESEARCH LAB</td>
<td>US NAVAL RESEARCH LAB</td>
</tr>
<tr>
<td>ATTN: DIR, MECH DIV</td>
<td>ATTN: DIR, MECH DIV</td>
</tr>
<tr>
<td></td>
<td>CODE 26-27 (DOC LIB)</td>
</tr>
<tr>
<td></td>
<td>WASHINGTON, D.C. 20375</td>
</tr>
<tr>
<td></td>
<td>NASA SCIENTIFIC &amp; TECH INFO FAC</td>
</tr>
<tr>
<td>NASA SCIENTIFIC &amp; TECH INFO FAC</td>
<td>NASA SCIENTIFIC &amp; TECH INFO FAC</td>
</tr>
<tr>
<td>P.O. BOX 8757, ATTN: ACQ BR</td>
<td>P.O. BOX 8757, ATTN: ACQ BR</td>
</tr>
<tr>
<td>BALTIMORE/WASHINGTON INTL AIRPORT</td>
<td>BALTIMORE/WASHINGTON INTL AIRPORT</td>
</tr>
<tr>
<td>MARYLAND 21240</td>
<td>MARYLAND 21240</td>
</tr>
</tbody>
</table>

NOTE: PLEASE NOTIFY COMMANDER, ARADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.