



Consumers  
Power  
Company

James W Cook

Vice President - Projects, Engineering  
and Construction

General Offices: 1945 West Parnall Road, Jackson, MI 49201 • (517) 788-0453

August 17, 1981

Harold R Denton, Director  
Office of Nuclear Reactor Regulation  
US Nuclear Regulatory Commission  
Washington, DC 20555



MIDLAND PROJECT

DOCKET NOS 50-329, 50-330

SOIL PRECONSOLIDATION PRESSURE VERSUS  
POSTOVERBURDEN PRESSURES OF THE  
DIESEL GENERATOR BUILDING

FILE: 0485.16 SERIAL: 13422

REFERENCES: J W COOK LETTER TO H R DENTON

1. SERIAL 11625, DATED MARCH 23, 1981
2. SERIAL 13382, DATED JULY 31, 1981

ENCLOSURES: 1. CONSOLIDATION TEST COMPARISON  
2. DR R B PECK'S EVALUATION  
OF THE BORING RESULTS

This letter, together with enclosures, finalize our presentation with respect to the additional borings program for the diesel generator building area. In our previous submittals on this subject, we provided the results of consolidation tests conducted on soil samples obtained from five borings in the area of the diesel generator building (Reference 2). In addition, we provided values of preconsolidation pressure of cohesive fill materials as determined by three geotechnical engineers using the Casagrande graphical technique.

We also supplied a comparison of preconsolidation values obtained by Woodward-Clyde Consultants for borings made before surcharging. For samples at the same elevation, the calculated pore consolidation pressures obtained from tests done by Woodward-Clyde Consultants in 1981 are in all but three cases (11 out of 14 cases) larger than those obtained from tests by Goldberg, Zoino, Dunnicliff & Associates (GZD) in 1978. This clearly demonstrates a gain in preconsolidation pressures as a consequence of surcharging at the diesel generator building.

To complete our commitment on this subject as described in Reference 1, we include herewith a comparison of preconsolidation stresses derived from the recent Woodward-Clyde borings with stresses calculated from the known loading conditions during surcharging. For convenience, we have indicated the calculated stress from loading conditions on the corresponding  $e$  log  $P$  plot for each sample. The calculated loading stress is indicated at the

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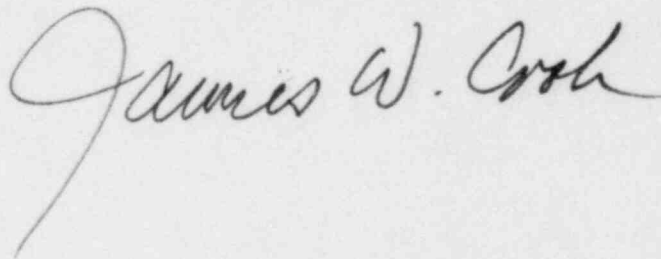
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appropriate value by an arrow on the respective  $e \log P$  plots. This information is provided as Enclosure 1.

We have also included in Enclosure 2 an evaluation of the boring results by Dr Ralph Peck. As an attachment, Dr Peck indicates the values of preconsolidation pressures obtained by Woodward-Clyde Consultants along with the calculated stresses during surcharging. The latter results are plotted as a smooth curve for each boring location, upon which the corresponding preconsolidation values obtained by Woodward Clyde have been superimposed.

The amount of scatter in data from these tests was expected and is inherent in the processes of boring, sampling, testing and calculation of the preconsolidation pressure. Our opinion is that the most reliable indications of future building behavior are the data obtained from the surcharge settlement measurements and piezometer readings.

While we have consistently taken the position that the additional borings requested by the NRC would not be helpful in confirming the effectiveness of the preload process; nevertheless, we agreed to carry out the borings and tests requested to enable the staff to complete their review. In conclusion, surcharging the subsoil of the diesel generator building served as a full proof test which was amply demonstrated by the settlement and pore pressure observations carried out during and after the surcharge program.



JWC/WJC/NR/dsb

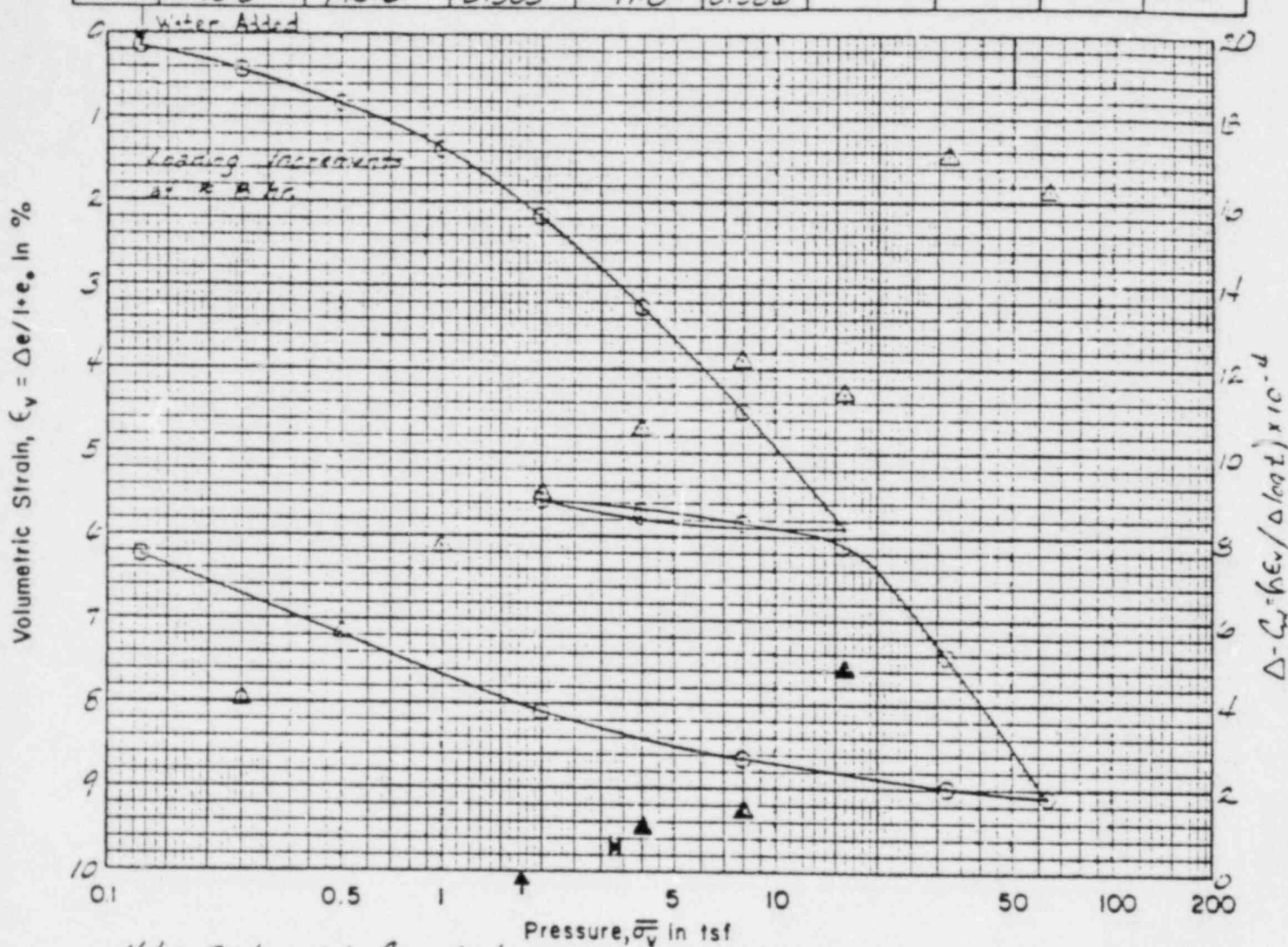
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Atomic Safety & Licensing Board Panel, w/o  
Charles Bechhoefer, Esq, w/o  
MMCherry, Esq, w/o  
RJCook, Midland Resident Inspector, w/o  
Dr FPCowan, w/o  
RSDecker, w/o  
NRC Docketing Service Section, w/a  
SGadler, w/o  
RWHuston, Washington, w/a  
JDKane, NRC, w/a  
FJKelley, Esq, w/o  
WHMarshall, w/o  
MIMiller, Esq, w/a  
WOtto, US Army Corps of Engineers, w/a  
WDPaton, Esq, w/o  
MSinclair, w/o  
BStamiris, w/o  
HSingh, US Army Corps of Engineers, w/a

ENCLOSURE 1  
Consolidation Test Comparison



# CONSOLIDATION TEST

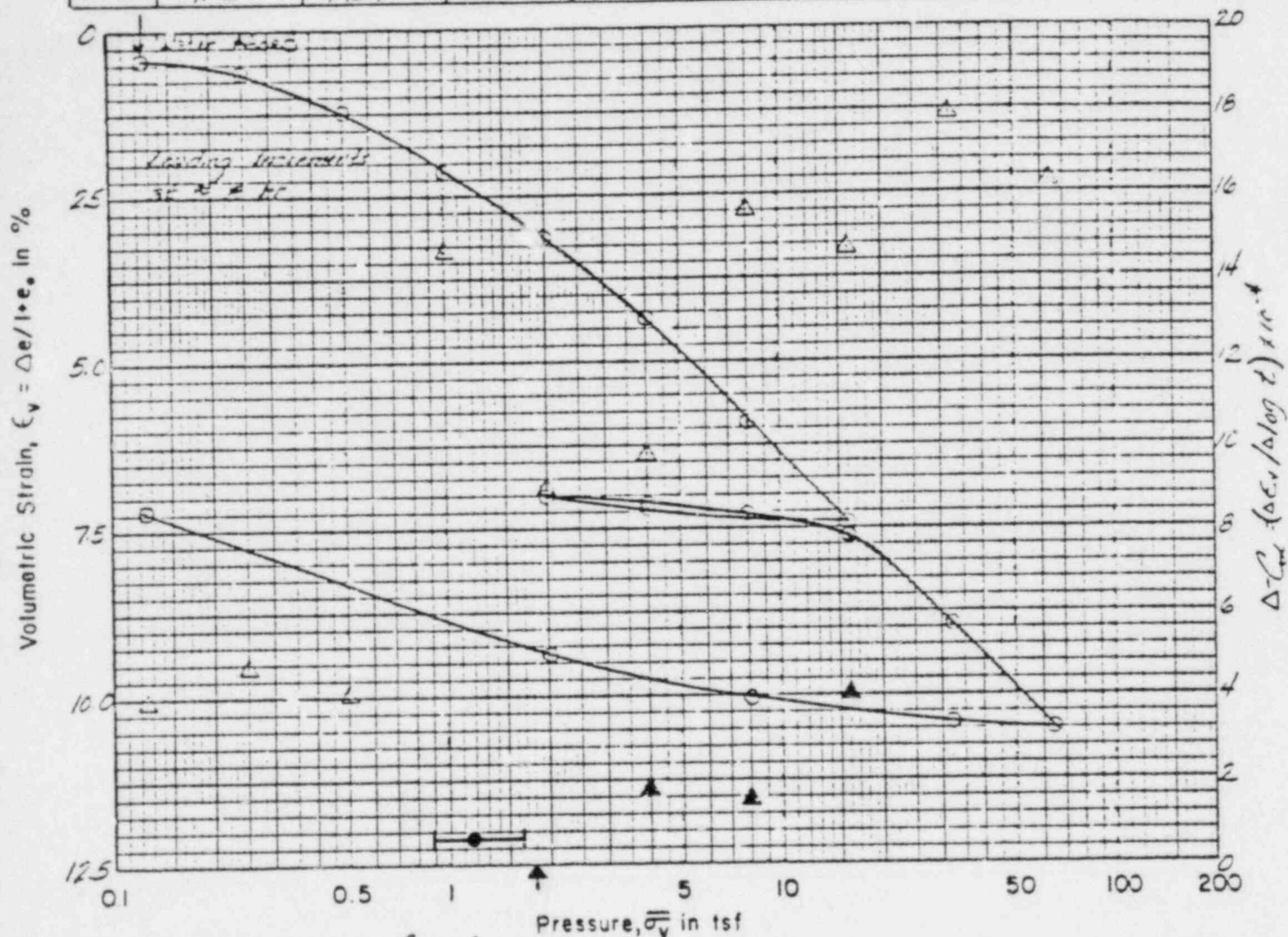
|   |                  |                        |            |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No. COE-11A  |                  | Sample No. S-2B        |            |               |                | Depth, ft 12.4   |                  |                 |                  |
| Material. CL, mottled gray & brown m.to. S sandy spt to mp silty CLAY, 11.5% gravel to coarse |                  |                        |            |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 10.5             | 138.6                  | 0.366      | 79.0          | 0.614          | 2.50             | 2.748            | 72              | 12               |
| Final   | 10.8             | 145.6                  | 0.303      | 97.8          | 0.586          |                  |                  |                 |                  |



Note: Solid symbols for reloading

# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: CDE-11A   |                  | Sample No: S-4B        |            |               |                | Depth, ft. 14.1  |                  |                 |                  |
| Material: CL, gr-br m. to S. sandy sp to mp silty CLAY, trace f. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 11.8             | 137.9                  | 0.359      | 83.3          | 0.614          | 2.50             | 2.747            | 22              | 12               |
| Final  | 11.6             | 145.1                  | 0.318      | 100.3         | 0.583          |                  |                  |                 |                  |

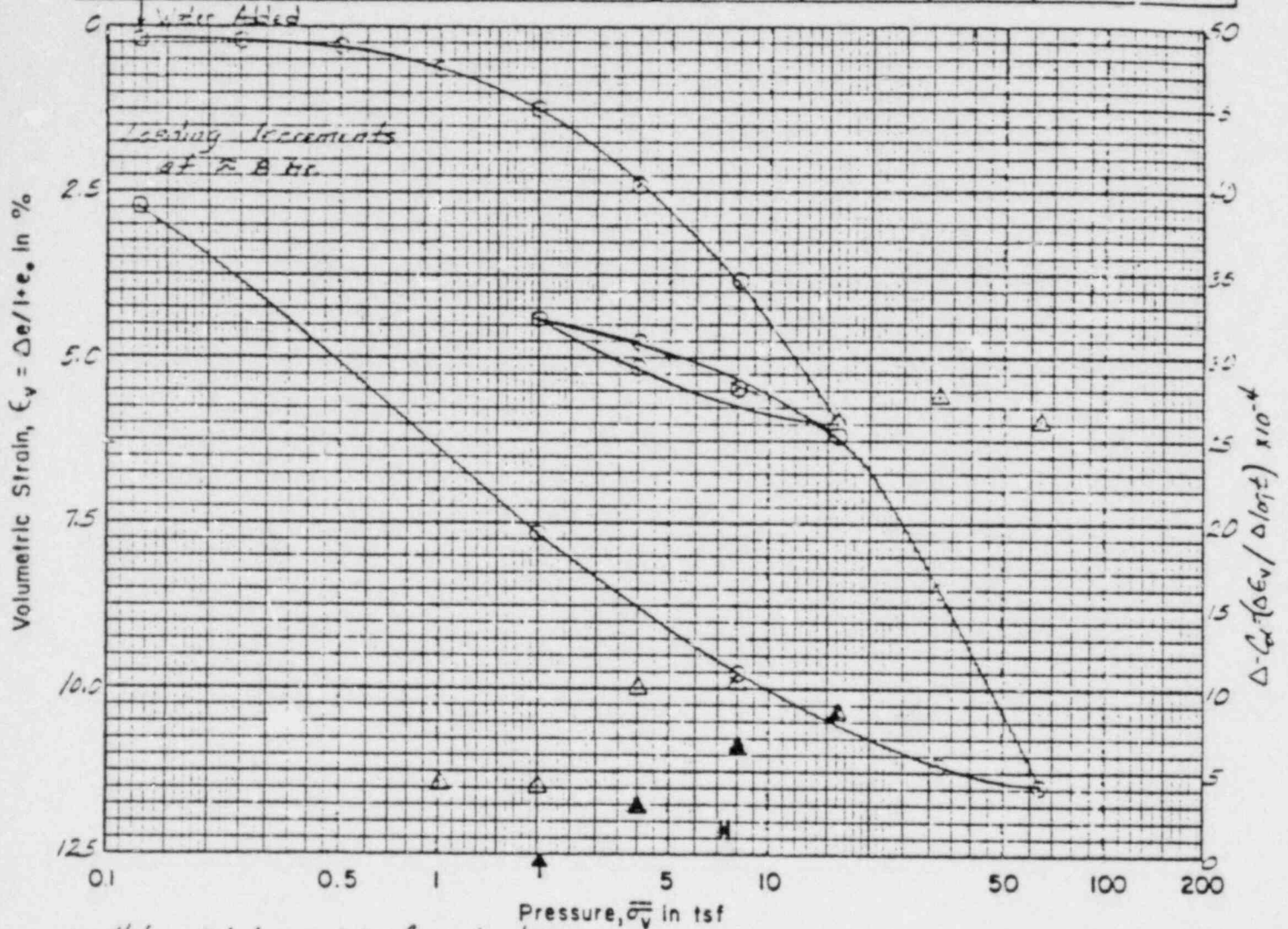


RANGE  
 MAXIMUM PAST CONSOLIDATION PRESSURE  
 AVERAGE

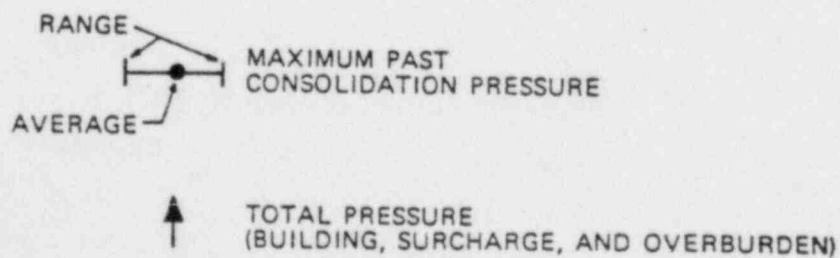
↑ TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)

# CONSOLIDATION TEST

|  |                  |                        |                 |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE 12 A  |                  |                        | Sample No: S-7C |               |                | Depth, ft: 20.8  |                  |                 |                  |
| Material: CL, mottled br. gr. & orange-br. plastic silty CLAY some m. to f. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 17.2             | 132.1                  | 0.519           | 91.2          | 0.614          | 2.50             | 2.747            | 38              | 17               |
| Final  | 19.7             | 131.6                  | 0.557           | 97.0          | 0.630          |                  |                  |                 |                  |



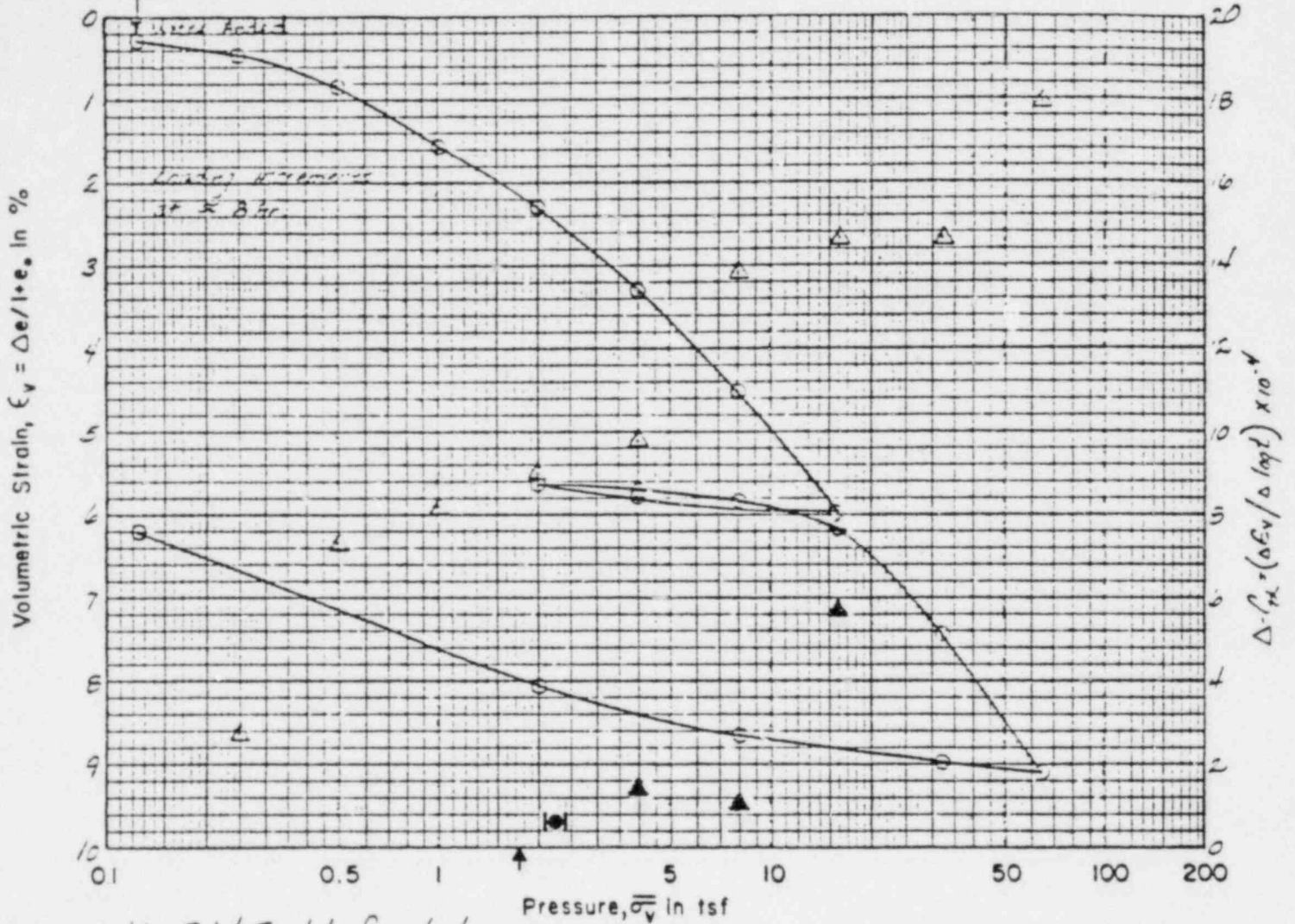
Note: Solid symbols for reloading



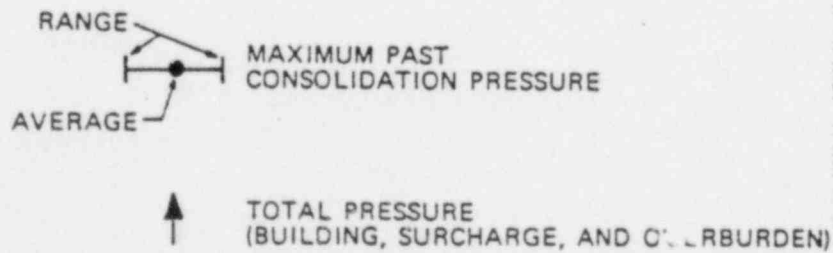


# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A  |                  |                        | Sample No: S2-D |               |                | Depth, ft: 9.6   |                  |                 |                  |
| Material: CL, br. m. s. sandy & p. silty CLAY, trace s. gravel to c. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 11.2             | 129.2                  | 0.376           | 82.4          | 0.614          | 2.50             | 2.764            | 21              | 13               |
| Final   | 10.8             | 125.3                  | 0.314           | 95.6          | 0.586          |                  |                  |                 |                  |

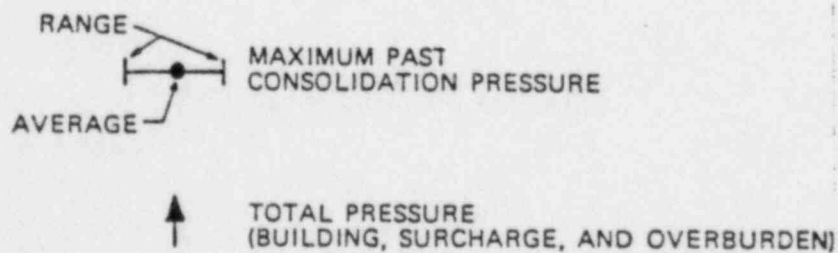
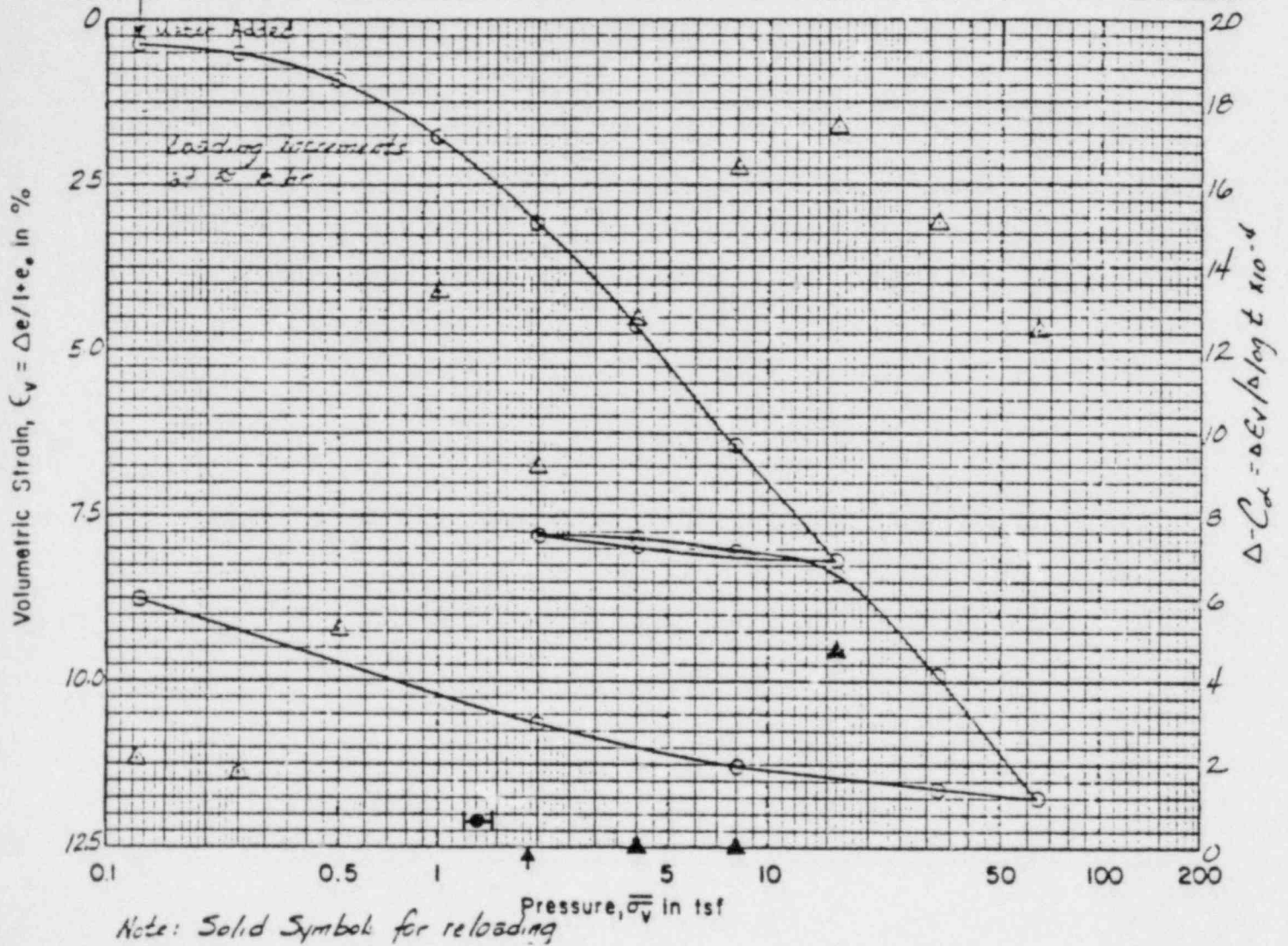


Note: Solid Symbols for reloading



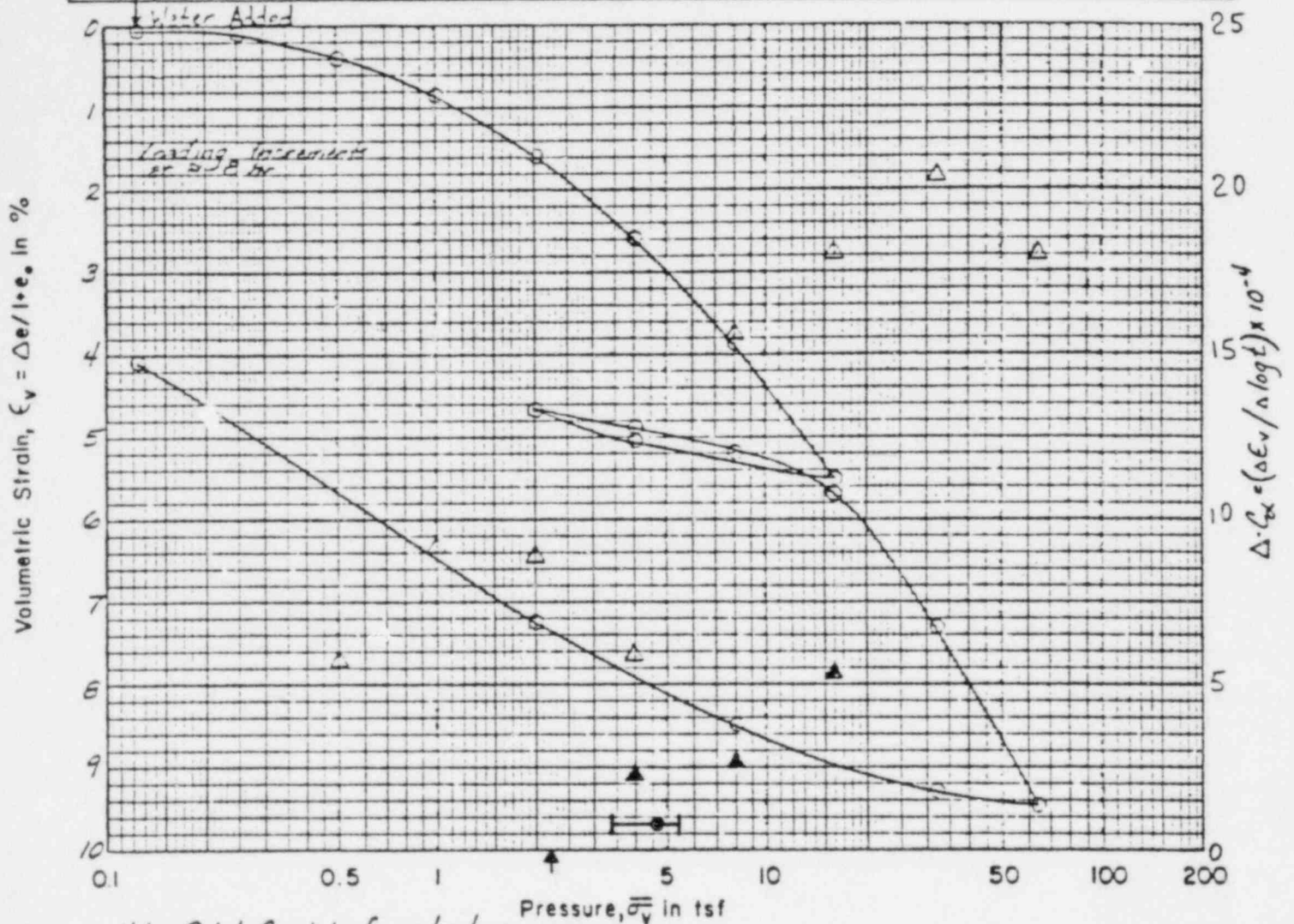
# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-11A   |                  | Sample No: S-5B        |            |               |                | Depth, ft. 16.7  |                  |                 |                  |
| Material: CL, gr-br m. to 5. sandy sp silty CLAY, trace S. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 12.1             | 135.1                  | 0.403      | 81.4          | 0.610          | 2.50             | 2.714            | 21              | 12               |
| Final  | 11.0             | 144.7                  | 0.297      | 100.4         | 0.564          |                  |                  |                 |                  |

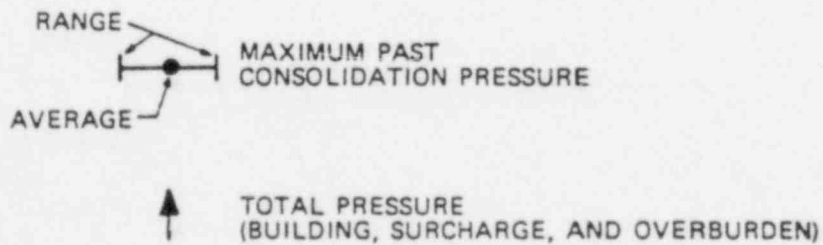


# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A   |                  | Sample No: S-8B        |            |               |                | Depth, ft. 23.0  |                  |                 |                  |
| Material: CL, mottled H. br, br & H or sp. silty CLAY, some f. gravel to f. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 14.6             | 135.9                  | 0.443      | 90.7          | 0.611          | 2.50             | 2.745            | 23              | 14               |
| Final  | 15.7             | 138.2                  | 0.433      | 99.8          | 0.606          |                  |                  |                 |                  |



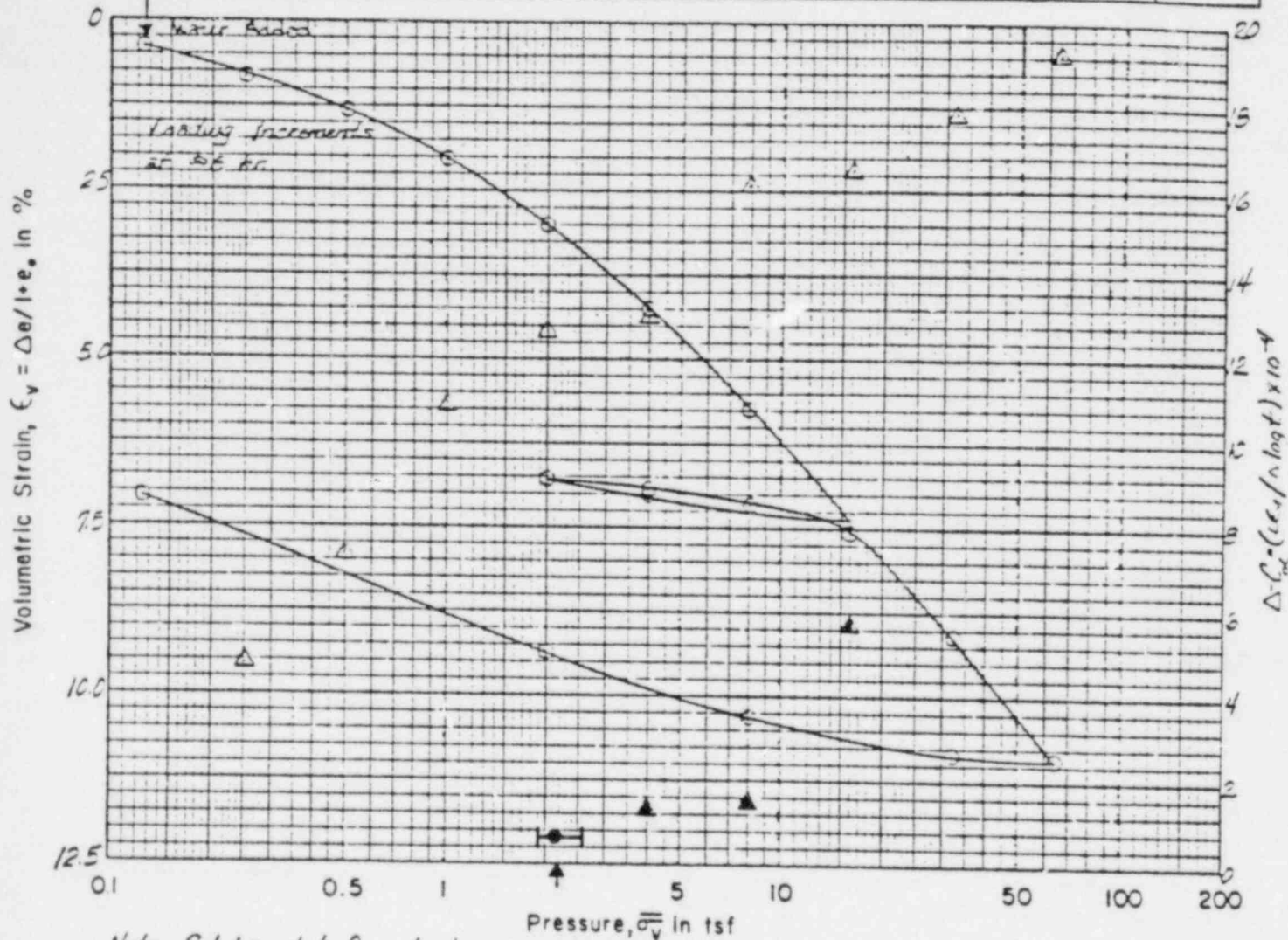
Note: Solid Symbols for reloading



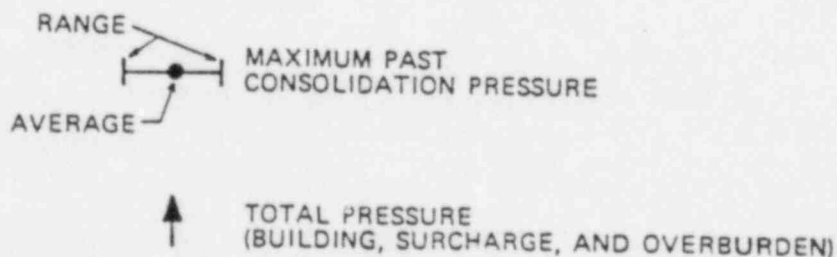


# CONSOLIDATION TEST

|  |                  |                        |                 |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-9A  |                  |                        | Sample No: S-8B |               |                | Depth, ft 19.9   |                  |                 |                  |
| Material: CL, br. & sandy m.p. s. H <sub>2</sub> CLAY, trace S gravel to m. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 13.8             | 137.5                  | 0.418           | 91.0          | 0.614          | 2.50             | 2.748            | 26              | 14               |
| Final  | 12.7             | 142.9                  | 0.351           | 99.9          | 0.585          |                  |                  |                 |                  |

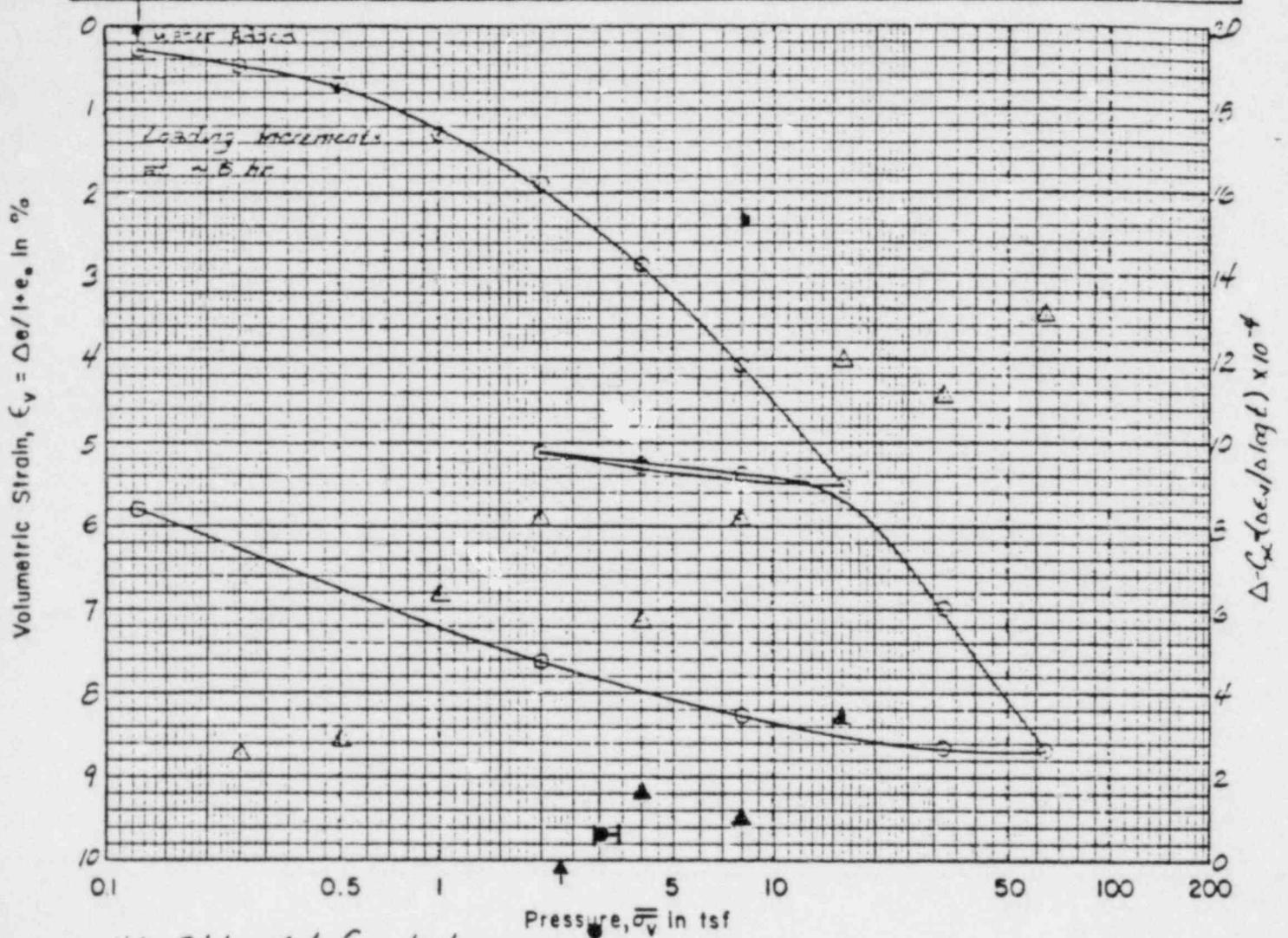


Note: Solid symbols for reloading



# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-13A  |                  |                        | Sample No: S-98 |               |                | Depth, ft 26.7   |                  |                 |                  |
| Material: CL, br. & sandy s.p. silty CLAY, trace S. gravel to m. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 10.4             | 142.1                  | 0.346           | 82.1          | 0.613          | 2.50             | 2.742            | 23              | 14               |
| Final   | 10.6             | 145.4                  | 0.300           | 97.1          | 0.592          |                  |                  |                 |                  |

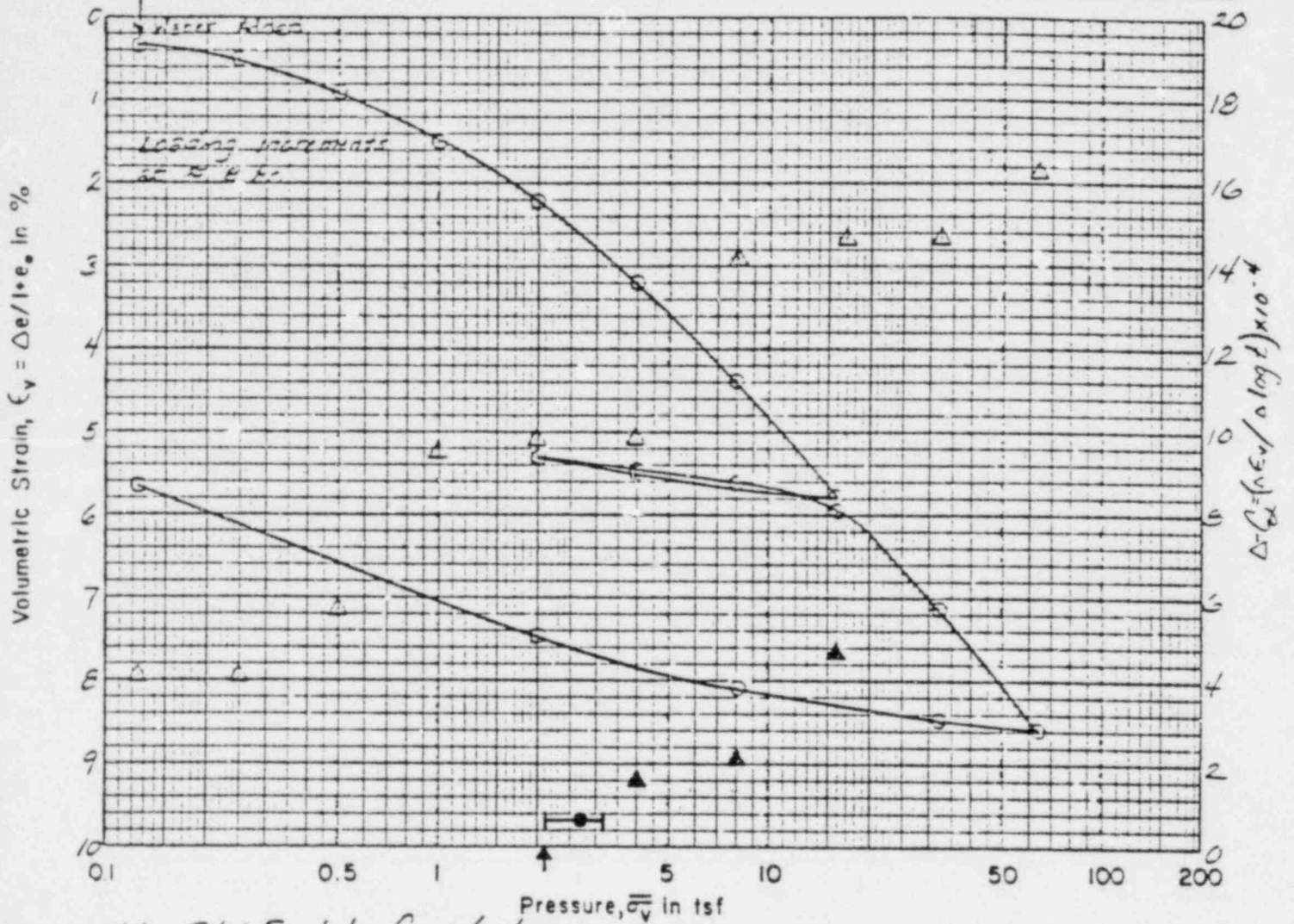


RANGE  
AVERAGE  
MAXIMUM PAST CONSOLIDATION PRESSURE

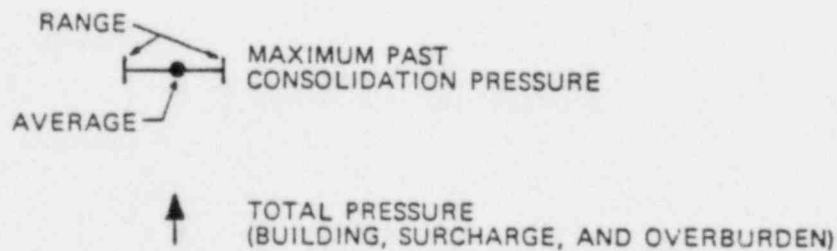
↑ TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)

# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: CCE-13B   |                  | Sample No: S-3D        |            |               |                | Depth, ft. 14.4  |                  |                 |                  |
| Material: CL-MIL, br. & sandy s.p. silty CLAY, trace c. to m. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 9.6              | 142.2                  | 0.315      | 83.1          | 0.612          | 2.50             | 2.740            | 19              | 13               |
| Final  | 9.8              | 147.6                  | 0.270      | 99.1          | 0.591          |                  |                  |                 |                  |



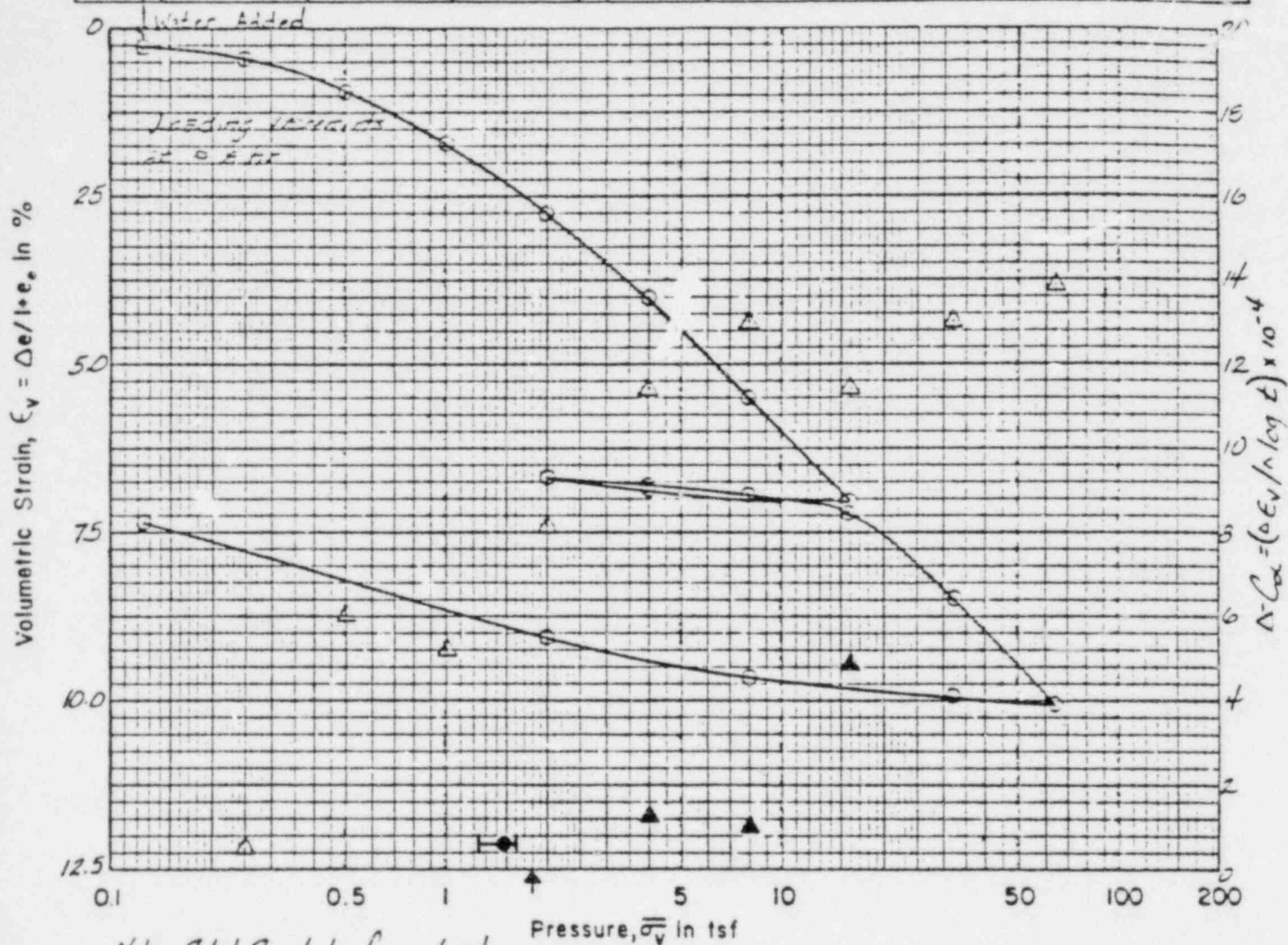
Note: Solid Symbols for reloading



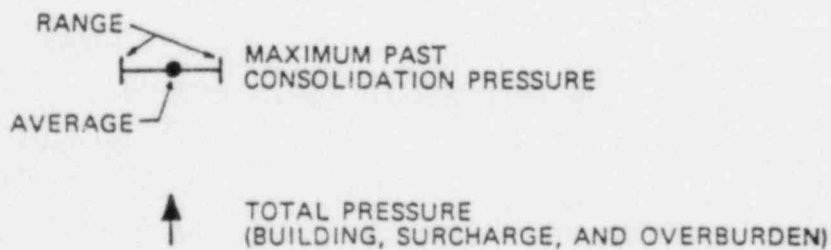


# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-13B  |                  |                        | Sample No: S-1B |               |                | Depth, ft 8.2    |                  |                 |                  |
| Material. CL, gr-br m to S. sandy spt to mp silty CLAY, trace S gravel to c. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 9.9              | 137.9                  | 0.365           | 74.4          | 0.613          | 2.50             | 2.743            | 23              | 13               |
| Final   | 10.0             | 145.9                  | 0.291           | 94.2          | 0.580          |                  |                  |                 |                  |

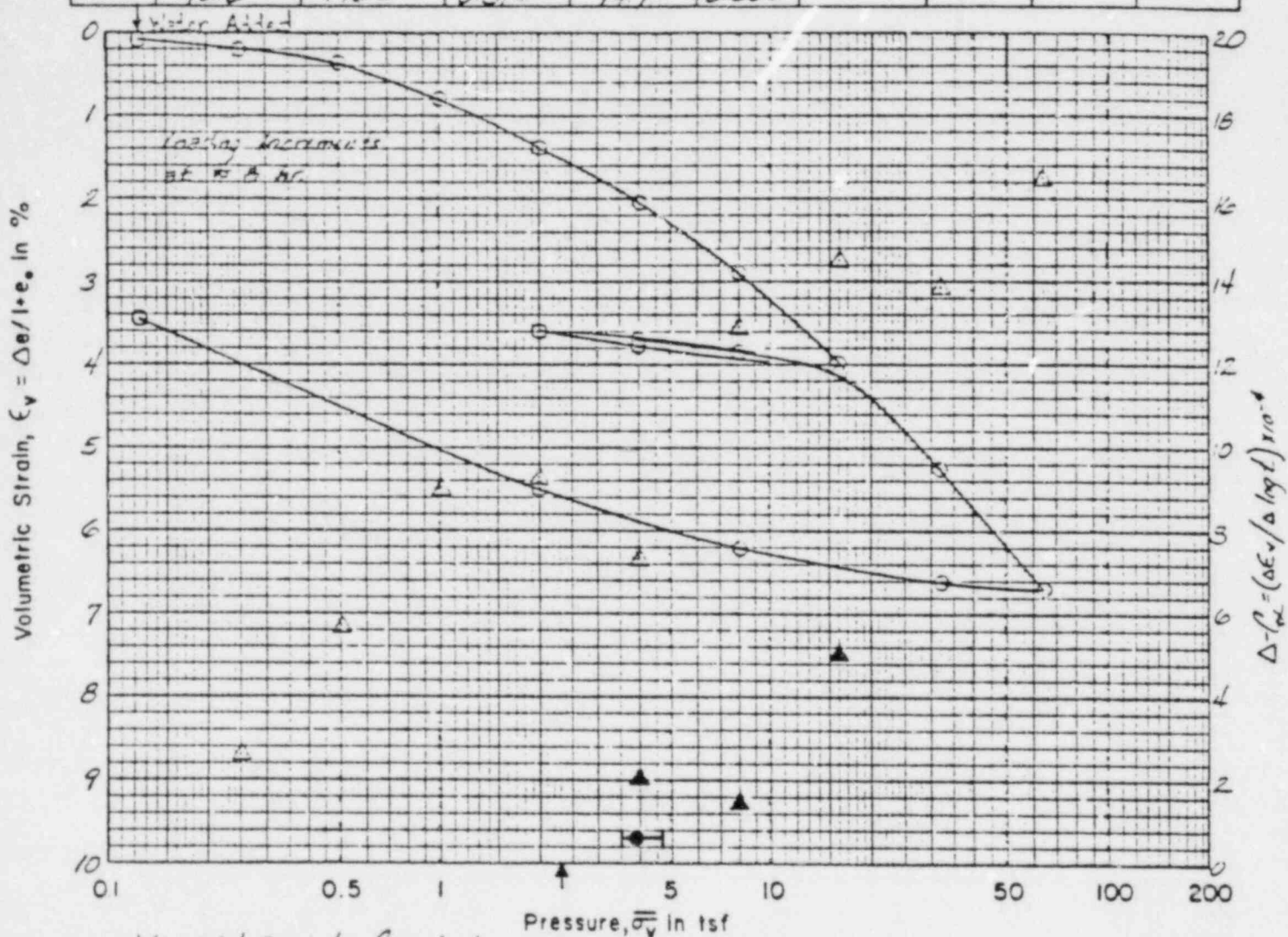


Note: Solid Symbols for reloading

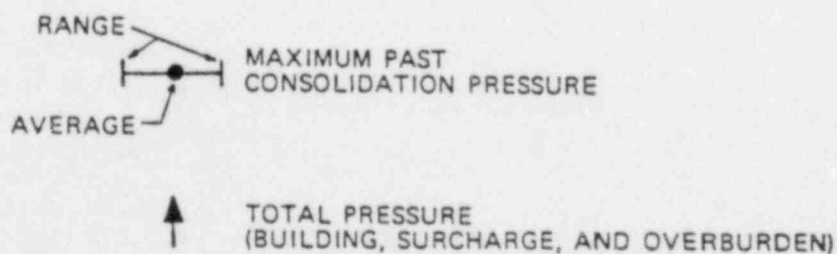


# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: CCE-13A   |                  | Sample No: S-6C        |            |               |                | Depth, ft. 22.4  |                  |                 |                  |
| Material: CL, br. m. t. f. sandy mp silty CLAY, trace s. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 10.9             | 144.9                  | 0.331      | 91.9          | 0.613          | 2.50             | 2.790            | 24              | 13               |
| Final  | 10.6             | 146.5                  | 0.314      | 94.7          | 0.605          |                  |                  |                 |                  |

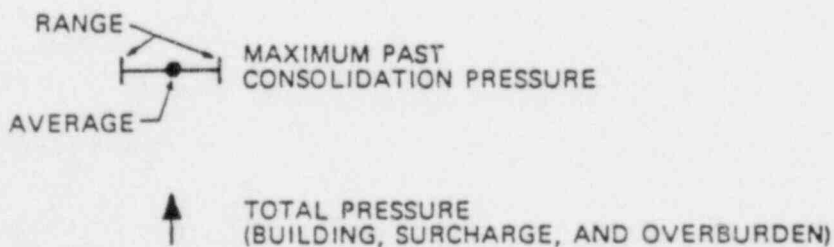
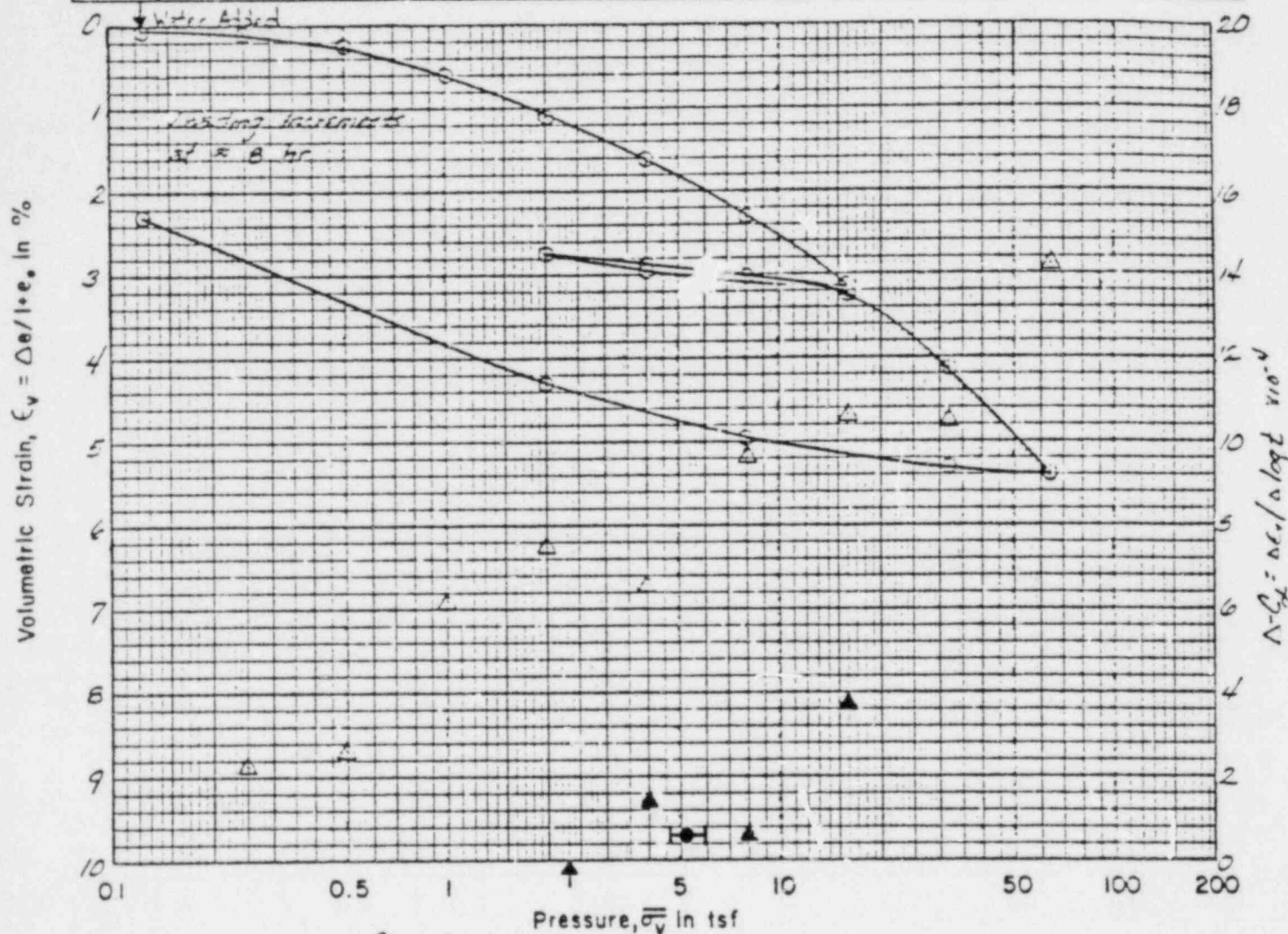


Note: Solid Symbols for reloading



# CONSOLIDATION TEST

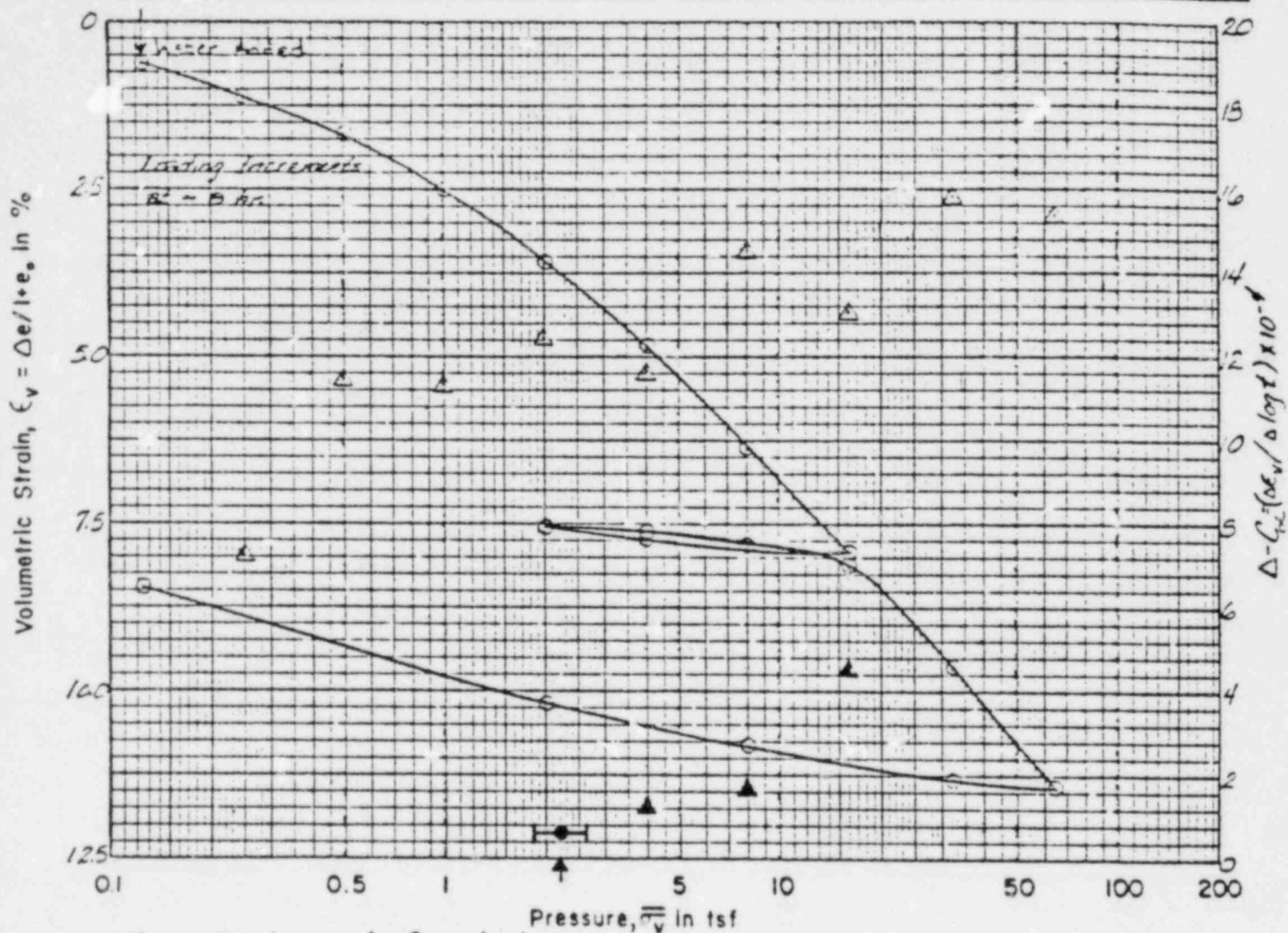
|  |                  |                        |              |               |                |                        |                  |                 |                  |
|--|------------------|------------------------|--------------|---------------|----------------|------------------------|------------------|-----------------|------------------|
| Boring No: <i>CF-13A</i>   |                  | Sample No: <i>S-5C</i> |              |               |                | Depth, ft: <i>21.1</i> |                  |                 |                  |
| Material: <i>CL, mottled br. &amp; orange-br s. sandy m.p. silty CLAY, tr. &amp; gravel to m. sand</i> |                  |                        |              |               |                |                        |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio   | Saturation, % | Height, inches | Diameter, inches       | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | <i>10.0</i>      | <i>145.4</i>           | <i>0.294</i> | <i>93.5</i>   | <i>0.611</i>   | <i>2.50</i>            | <i>2.745</i>     | <i>24</i>       | <i>13</i>        |
| Final  | <i>10.1</i>      | <i>145.9</i>           | <i>0.292</i> | <i>95.5</i>   | <i>0.610</i>   |                        |                  |                 |                  |



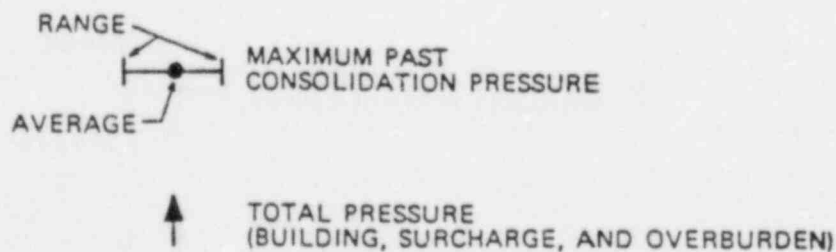


# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-13A   |                  | Sample No: S-4B        |            |               |                | Depth, ft. 13.2  |                  |                 |                  |
| Material: CL, gr-br m.t.s sandy sp silty CLAY, trace S gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 12.1             | 136.5                  | 0.410      | 81.4          | 0.619          | 2.50             | 2.754            | 21              | 12               |
| Final  | 10.6             | 146.6                  | 0.294      | 99.3          | 0.565          |                  |                  |                 |                  |

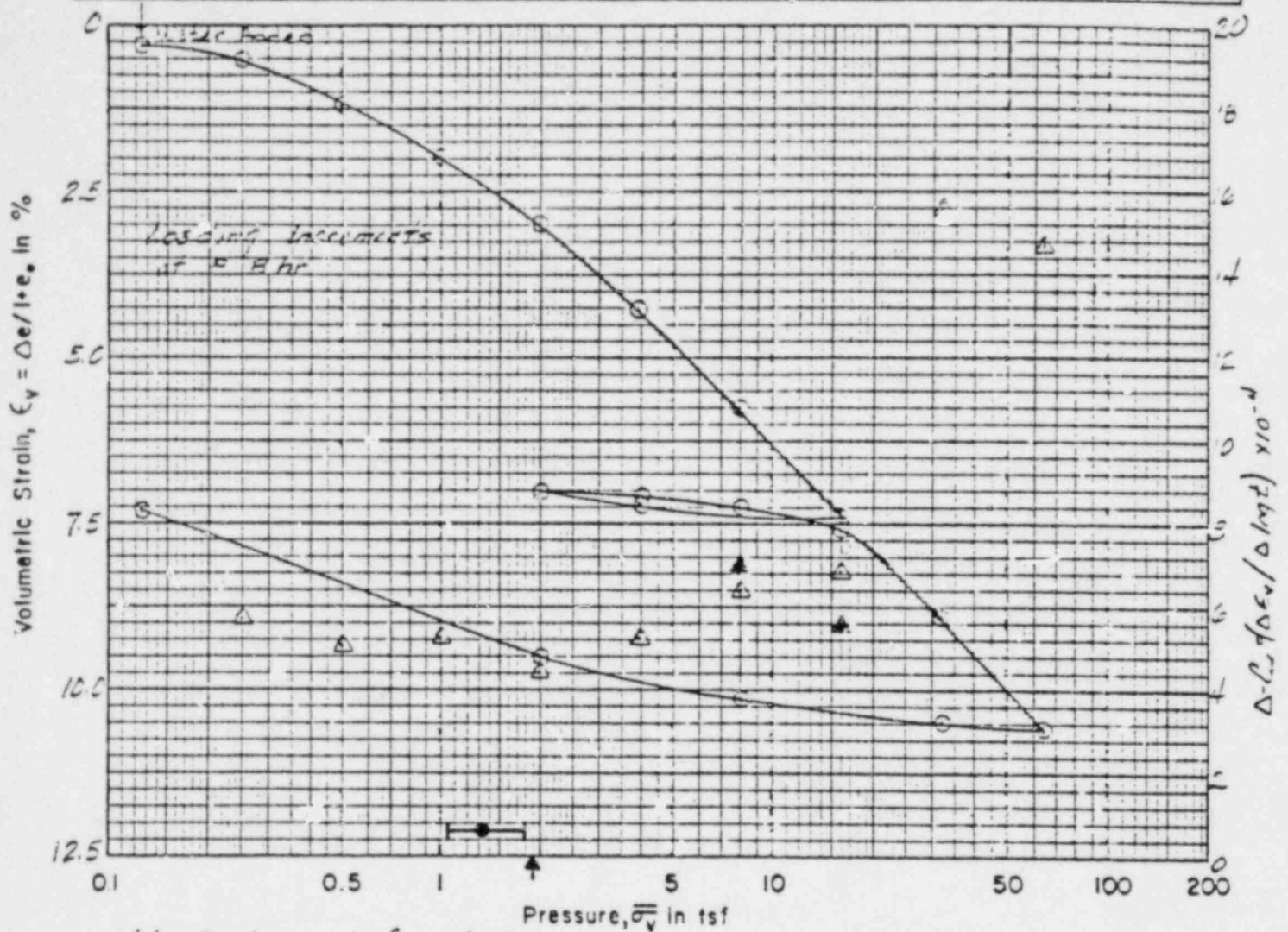


Note: Solid symbols for reloading

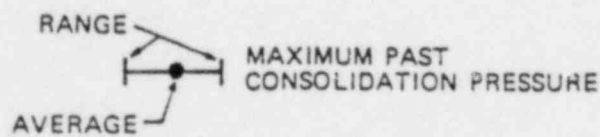


# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE 10A  |                  |                        | Sample No: S-1B |               |                | Depth, ft. 11.2  |                  |                 |                  |
| Material: CL-MIL, gr-br m to 5 sandy slightly plastic silty CLAY, trace 5 gravel to c. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 11.1             | 137.2                  | 0.379           | 79.9          | 0.613          | 2.50             | 2.734            | 20              | 13               |
| Final   | 10.4             | 145.6                  | 0.291           | 97.2          | 0.574          |                  |                  |                 |                  |



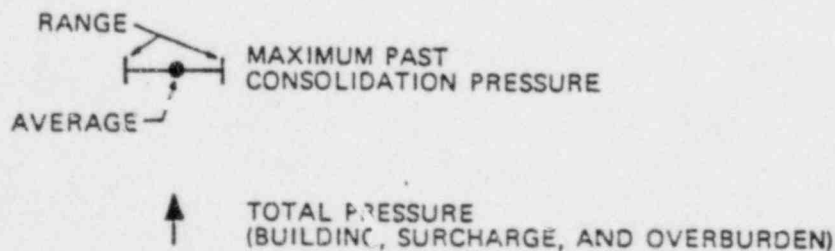
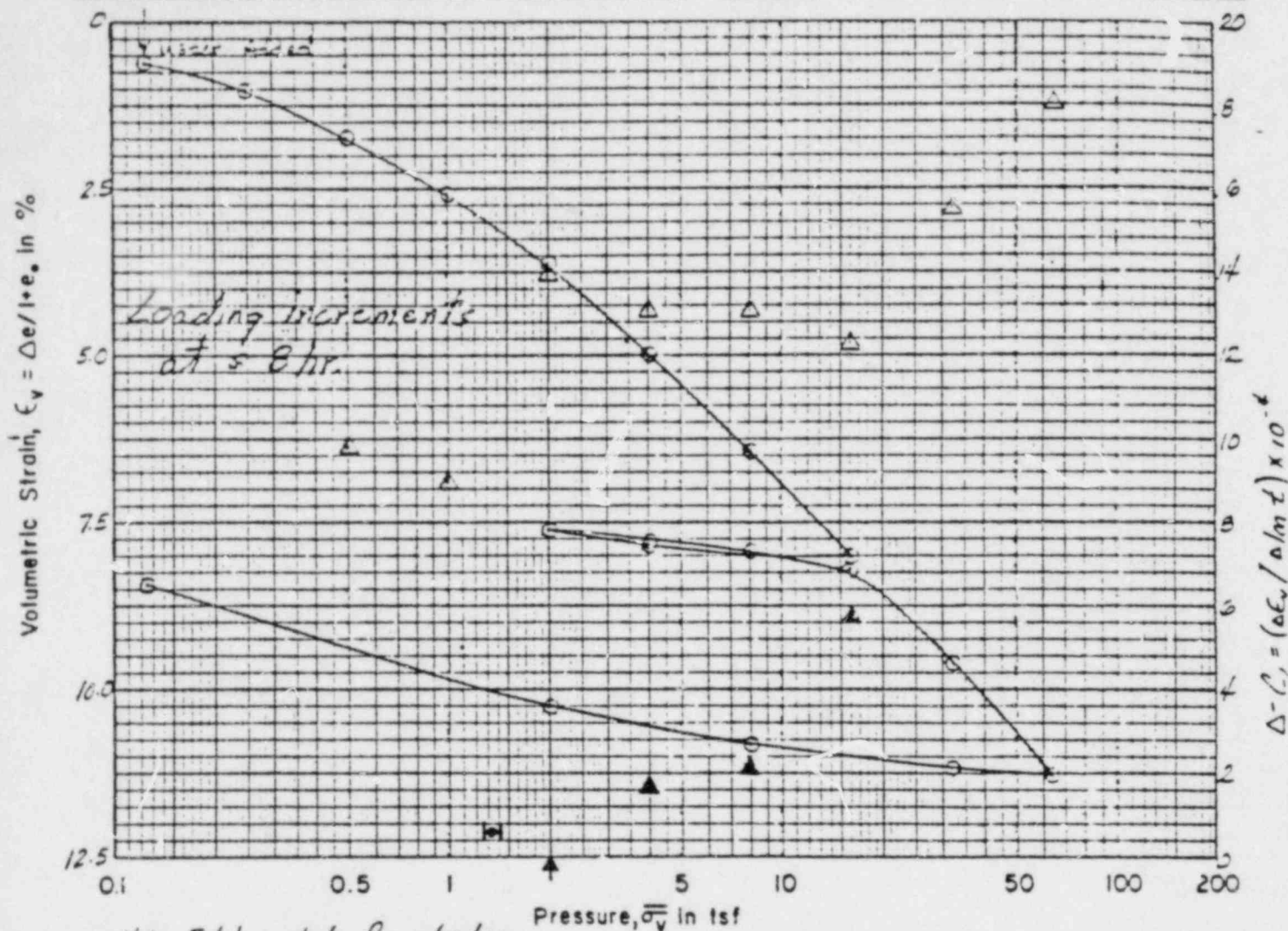
Note: Solid symbols for reloading



↑ TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)

# CONSOLIDATION TEST

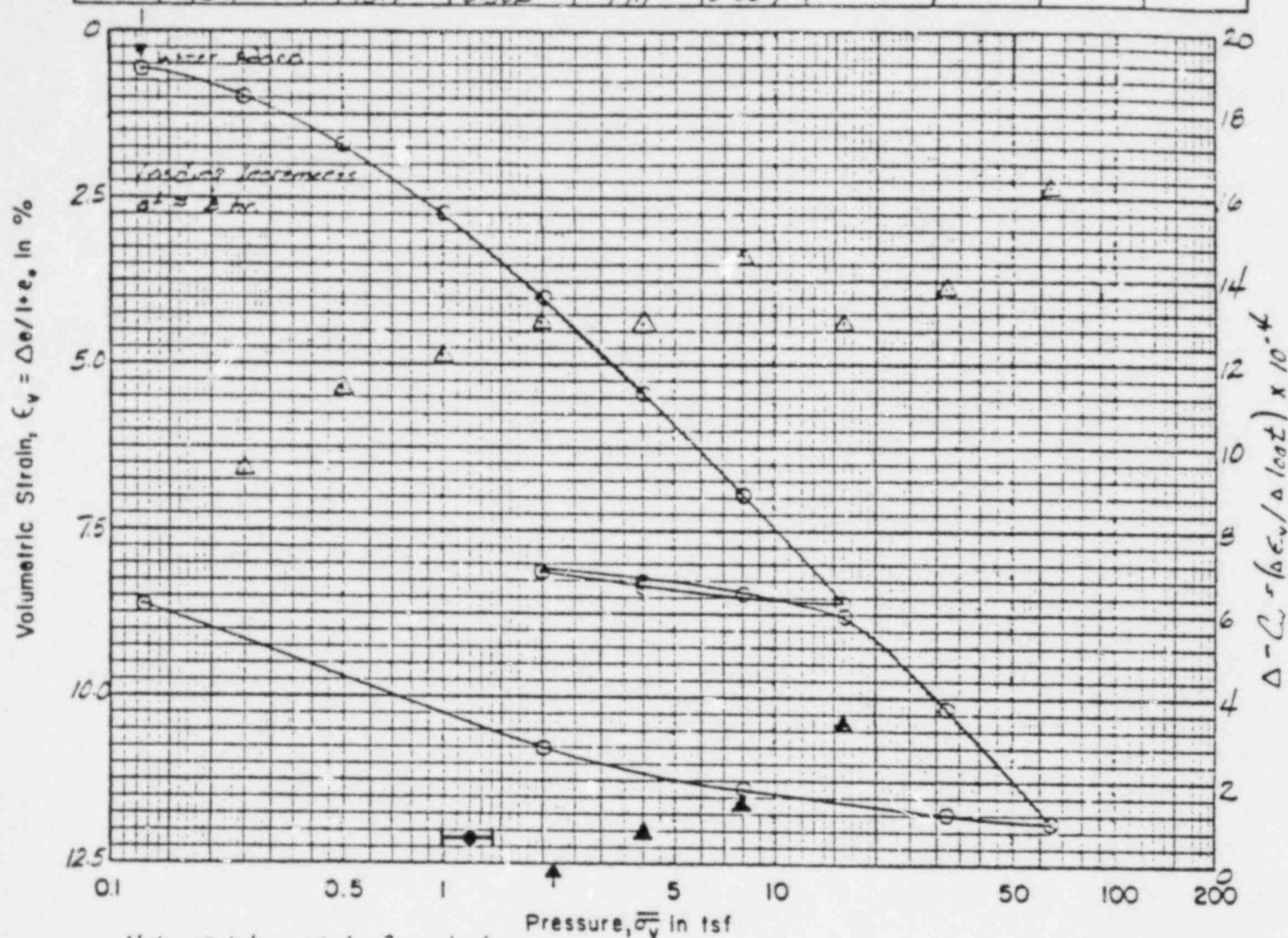
|   |                  |                        |              |               |                        |                  |                  |                 |                  |
|---|------------------|------------------------|--------------|---------------|------------------------|------------------|------------------|-----------------|------------------|
| Boring No: <i>CEE-9</i>   |                  | Sample No: <i>S-4A</i> |              |               | Depth, ft: <i>11.0</i> |                  |                  |                 |                  |
| Material: <i>CL, br. m. to s. sandy s.p. silty CLAY, trace s. gravel to c. sand</i> |                  |                        |              |               |                        |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio   | Saturation, % | Height, inches         | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | <i>12.3</i>      | <i>137.9</i>           | <i>0.393</i> | <i>85.9</i>   | <i>2.611</i>           | <i>2.50</i>      | <i>2.745</i>     | <i>20</i>       | <i>12</i>        |
| Final   | <i>10.5</i>      | <i>145.3</i>           | <i>0.301</i> | <i>95.8</i>   | <i>0.571</i>           |                  |                  |                 |                  |



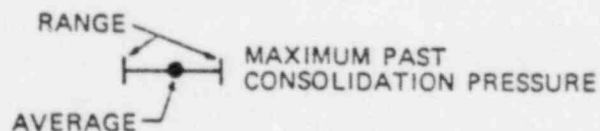


# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: CCE-9   |                  | Sample No: S-6B        |            |               |                | Depth, ft: 16.2  |                  |                 |                  |
| Material: CL, br. m to s sandy s.p. silty CLAY, trace S. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 12.1             | 136.6                  | 0.402      | 81.9          | 0.615          | 2.50             | 2.751            | 22              | 14               |
| Final  | 10.7             | 145.7                  | 0.302      | 97.1          | 0.569          |                  |                  |                 |                  |



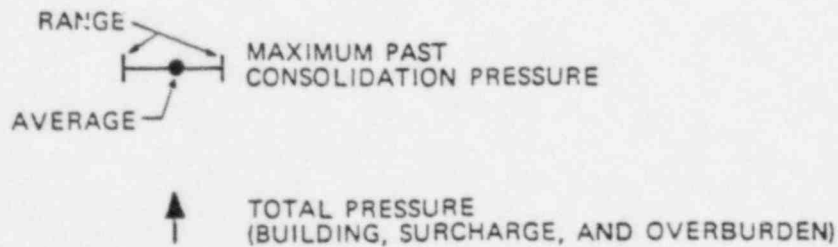
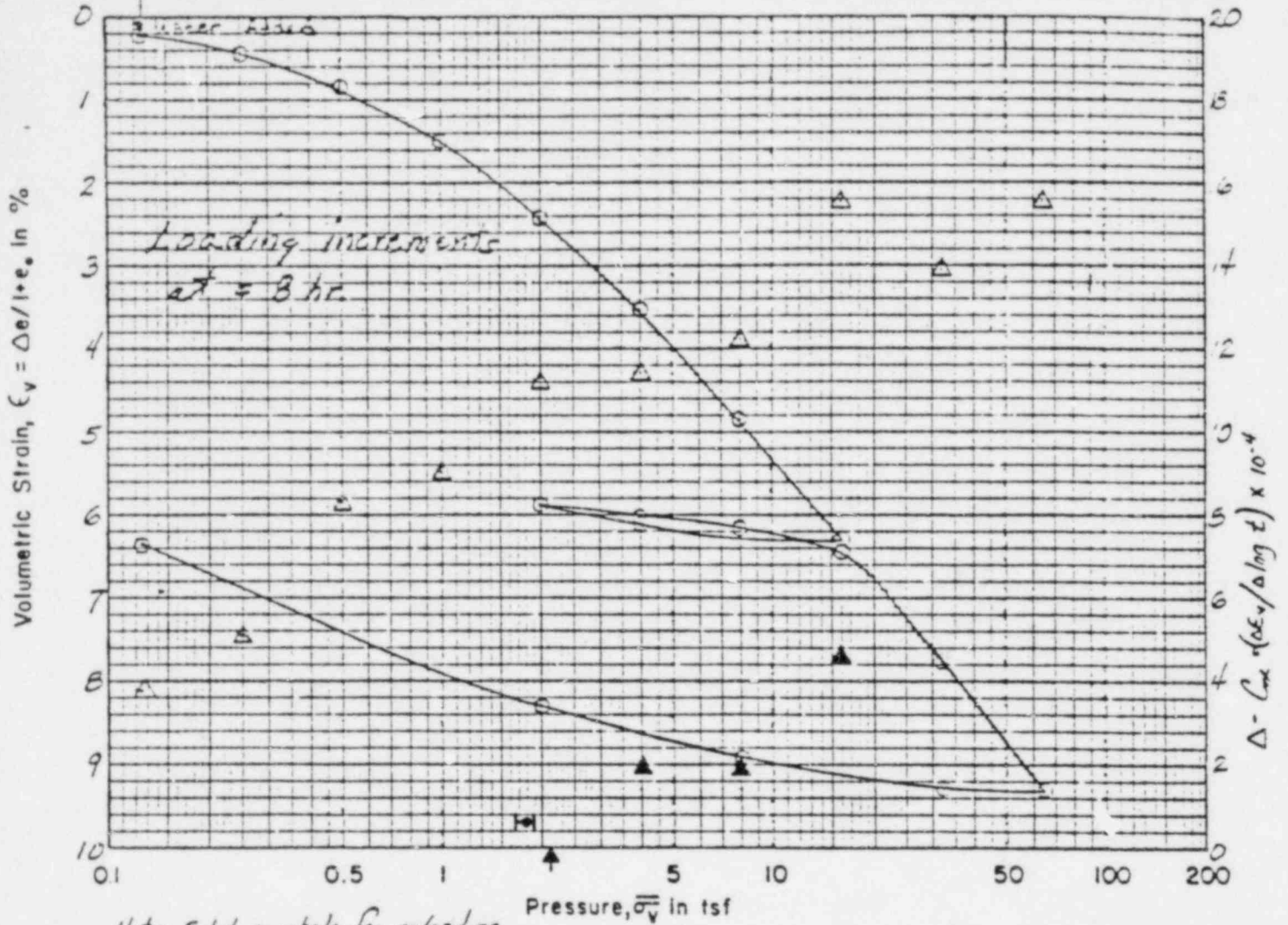
Note: Solid symbols for reloading



↑ TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)

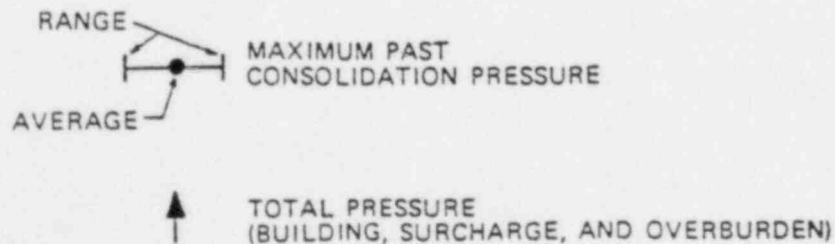
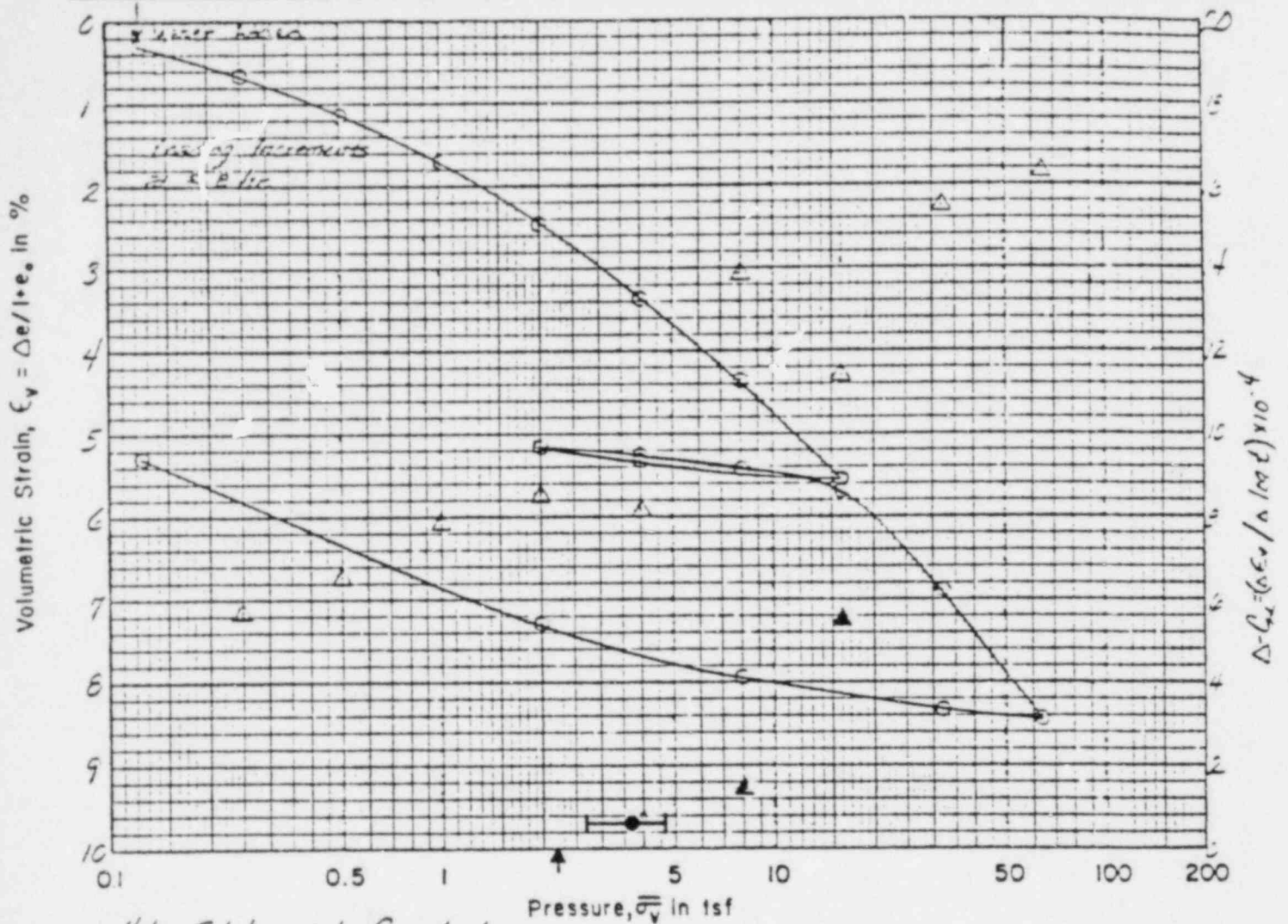
# CONSOLIDATION TEST

|   |                  |                        |            |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: 025-9  |                  | Sample No: S-35A       |            |               |                | Depth, ft: 14.0  |                  |                 |                  |
| Material: CL, brown & sandy s.p. silt, CLAY, trace & gravel to m sand |                  |                        |            |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 11.0             | 139.3                  | 0.357      | 84.5          | 0.611          | 2.50             | 2.732            | 21              | 13               |
| Final   | 10.3             | 147.0                  | 0.277      | 101.6         | 0.575          |                  |                  |                 |                  |



# CONSOLIDATION TEST

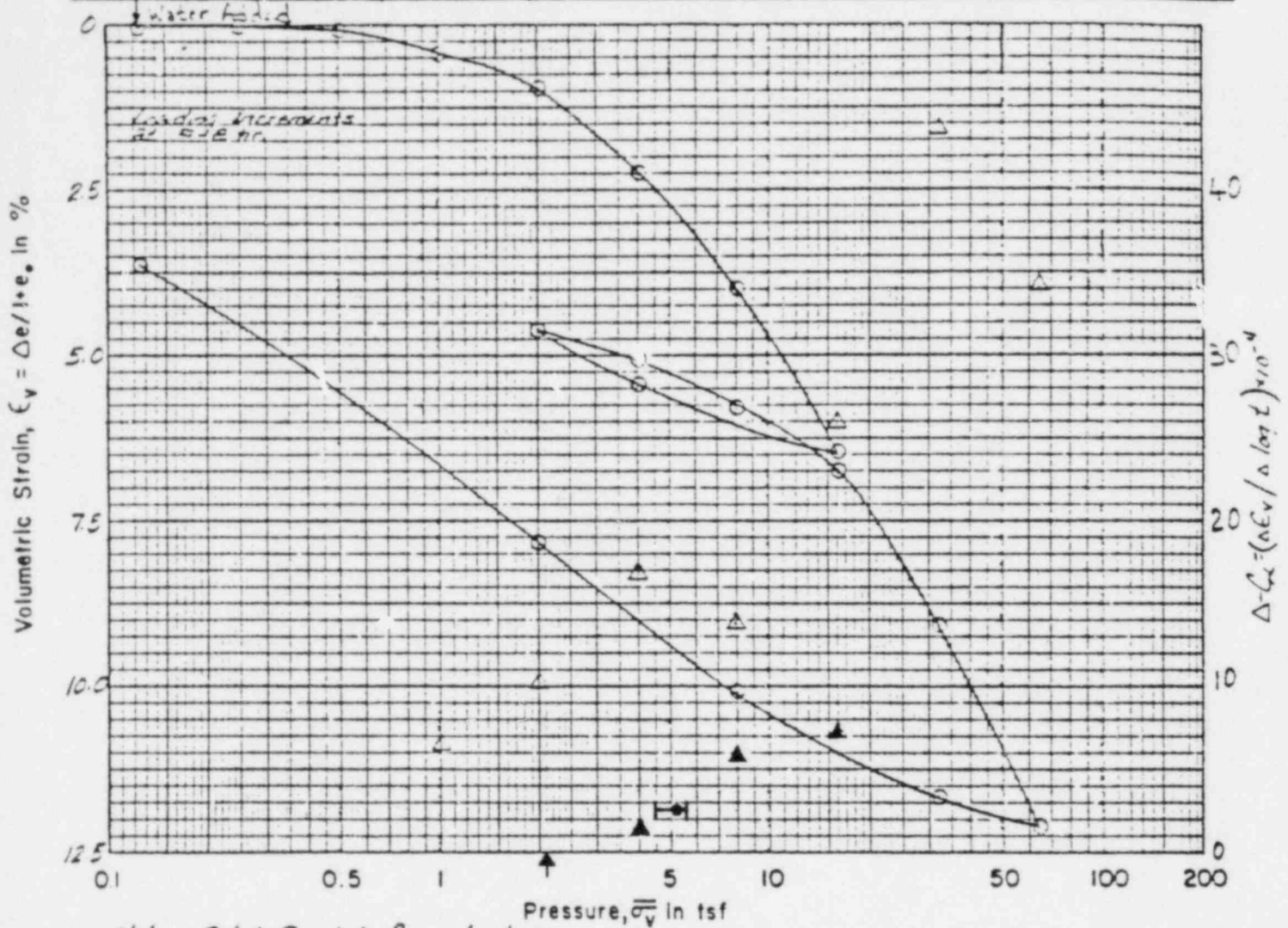
|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No. CEE-13A  |                  |                        | Sample No. S-30 |               |                | Depth, ft. 16.5  |                  |                 |                  |
| Material. CL, gr-br & sandy s.p. silty CLAY, some & gravel to m. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 11.0             | 142.6                  | 0.325           | 92.0          | 0.613          | 2.50             | 2.733            | 20              | 12               |
| Final   | 10.1             | 145.7                  | 0.236           | 94.1          | 0.595          |                  |                  |                 |                  |



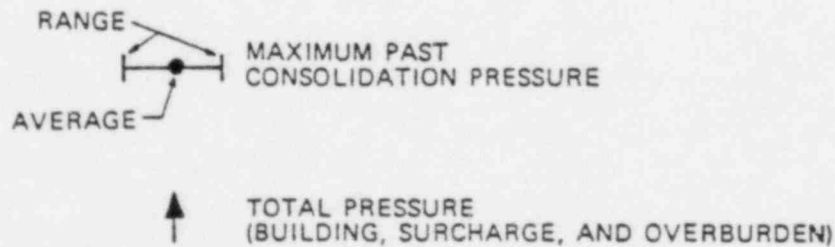


# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A  |                  |                        | Sample No: S-6B |               |                | Depth, ft: 19.0  |                  |                 |                  |
| Material: CL, mottled br, gr and red-br plastic silty CLAY, some m.to s. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 18.0             | 132.3                  | 0.542           | 92.3          | 0.617          | 2.50             | 2.774            | 46              | 13               |
| Final   | 19.6             | 131.9                  | 0.567           | 95.7          | 0.627          |                  |                  |                 |                  |

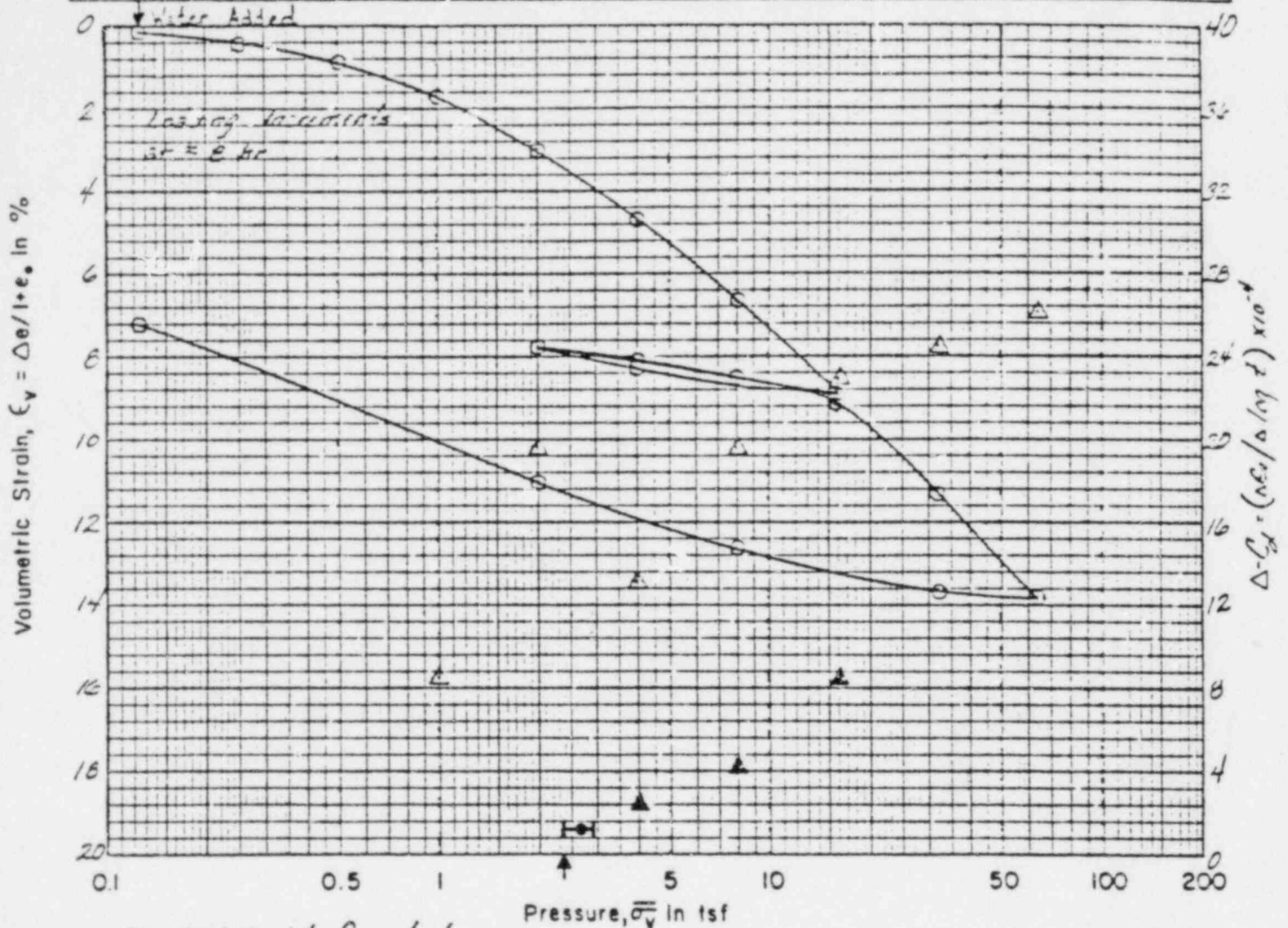


Note: Solid Symbols for reloading

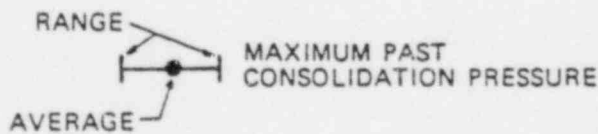


# CONSOLIDATION TEST

|   |                  |                        |                  |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|------------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A  |                  |                        | Sample No: S-10B |               |                | Depth, ft 28.0   |                  |                 |                  |
| Material: CL, brown m.p. silty CLAY, some S sand, trace c to m sand |                  |                        |                  |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio       | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 18.8             | 121.1                  | 0.542            | 94.6          | 0.612          | 2.50             | 2.732            | 34              | 15               |
| Final   | 18.9             | 122.5                  | 0.517            | 100.0         | 0.602          |                  |                  |                 |                  |



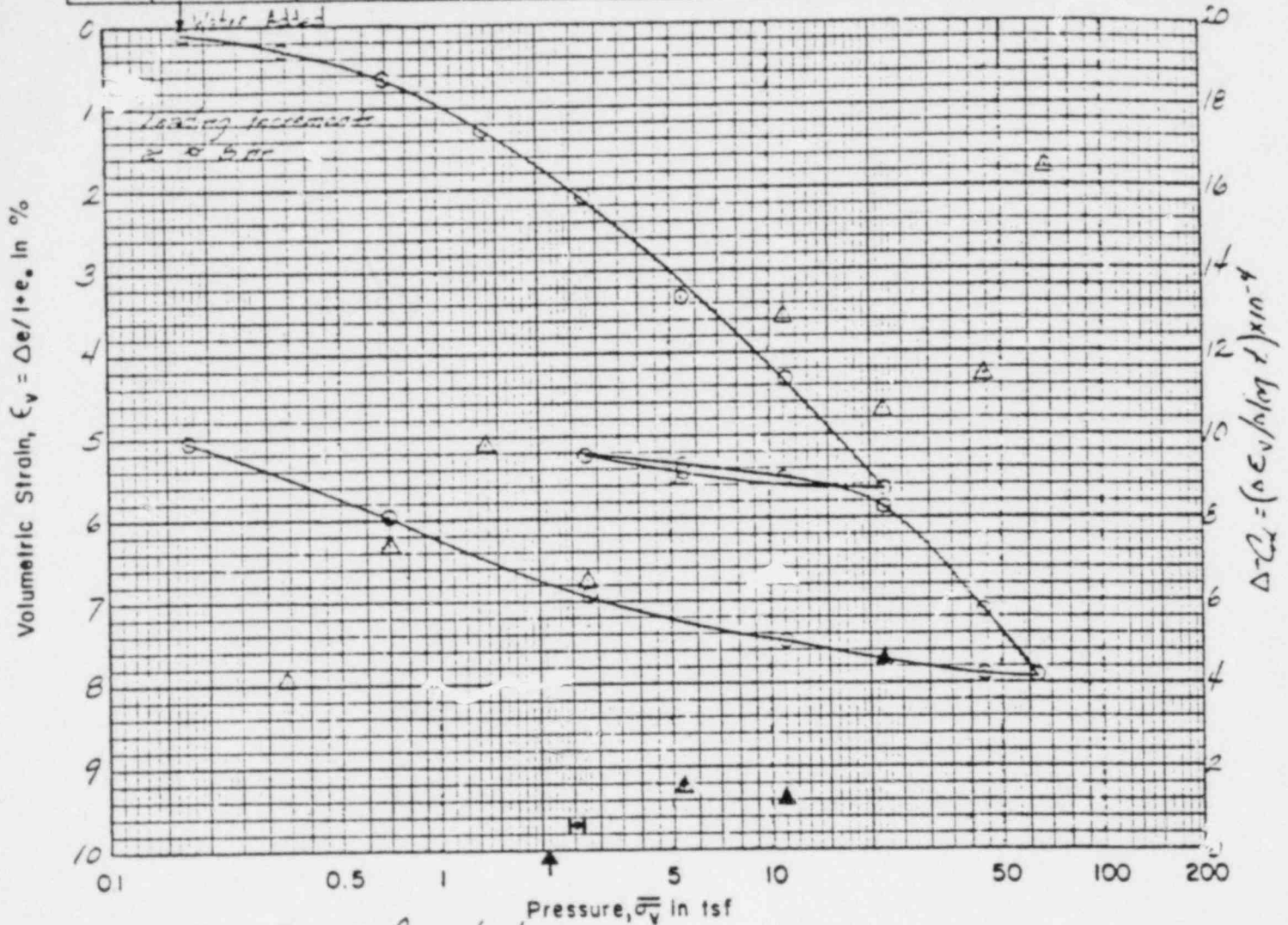
Note: Solid Symbols for reloading



TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)

# CONSOLIDATION TEST

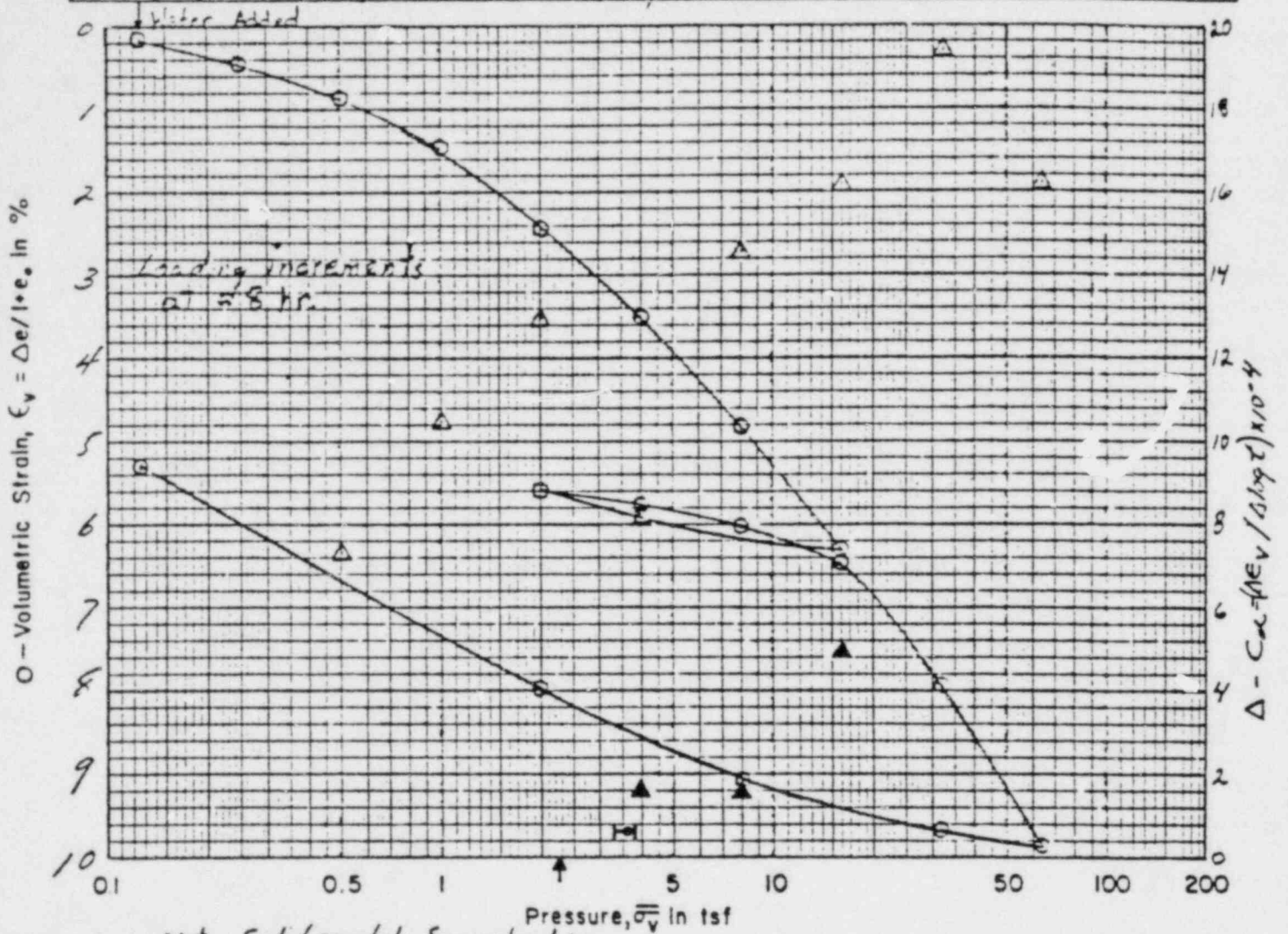
|   |                  |                        |            |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: CDE-12A  |                  | Sample No: S-5C        |            |               |                |                  | Depth, ft. 16.9  |                 |                  |
| Material: CL, mottled br. gr. & lt. br. n. to s. sandy sp silty CLAY, some s. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 9.7              | 141.5                  | 0.345      | 78.4          | 0.611          | 2.50             | 2.723            | 21              | 12               |
| Final   | 9.4              | 146.1                  | 0.299      | 87.7          | 0.590          |                  |                  |                 |                  |



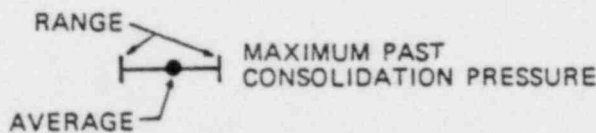
Note: Solid Symbols for reloading

# CONSOLIDATION TEST

|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A  |                  |                        | Sample No: S-9B |               |                | Depth, ft. 2.51  |                  |                 |                  |
| Material: CL, brown med plastic silty CLAY, some s. gravel to s. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 14.5             | 125.0                  | 0.470           | 85.7          | 1.618          | 2.50             | 2.783            | 2.8             | 13               |
| Final   | 14.8             | 139.2                  | 0.431           | 95.7          | .601           |                  |                  |                 |                  |



Note: Solid symbols for reloading

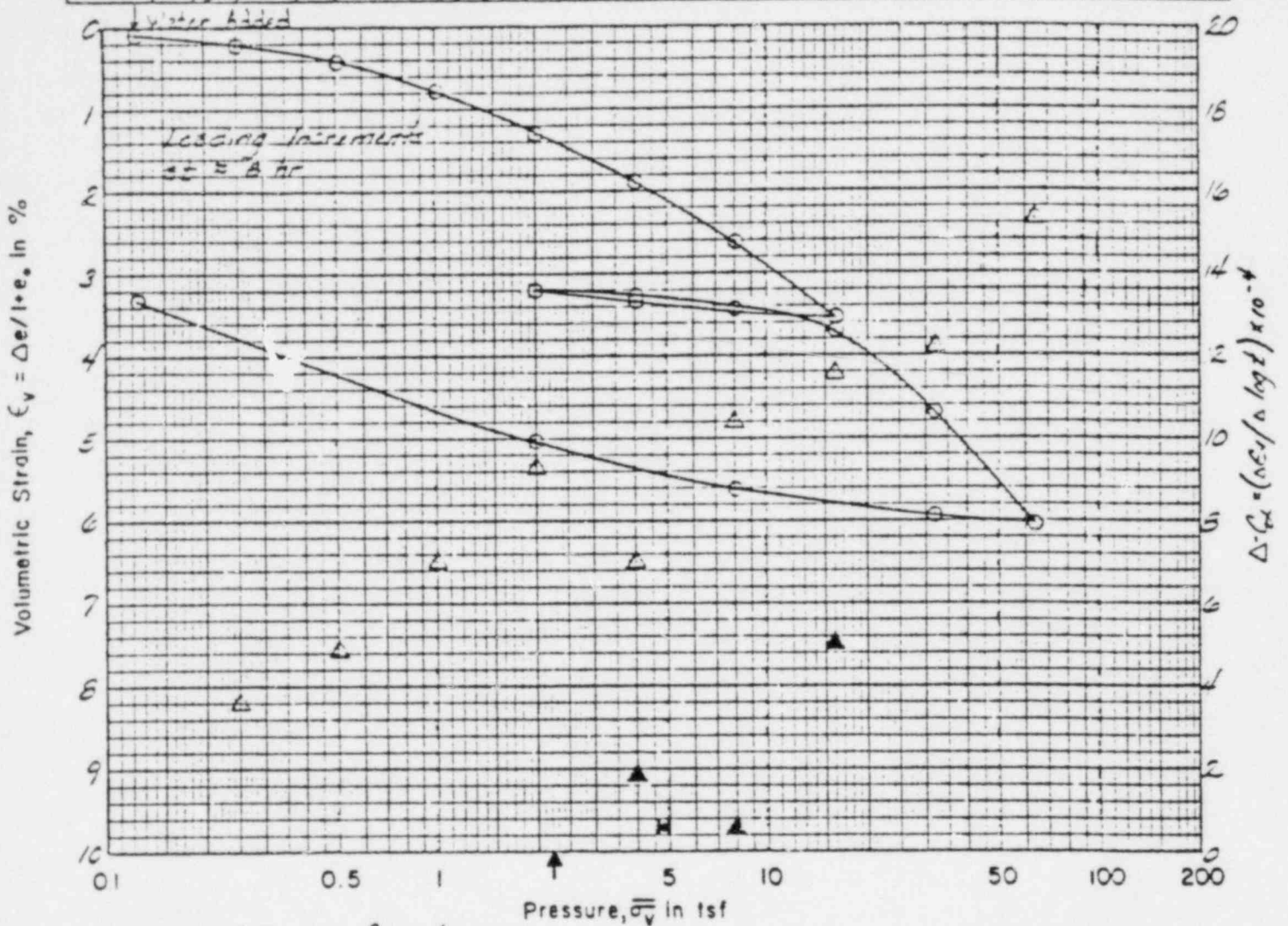


↑ TOTAL PRESSURE (BUILDING, SURCHARGE, AND OVERBURDEN)



# CONSOLIDATION TEST

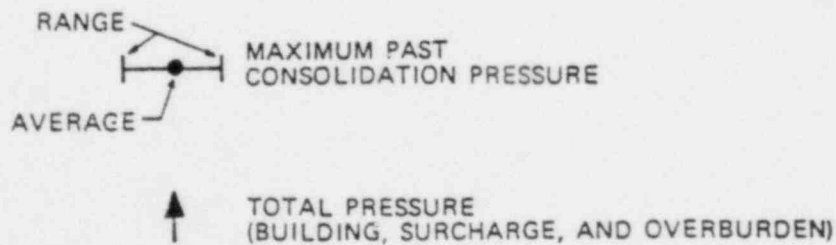
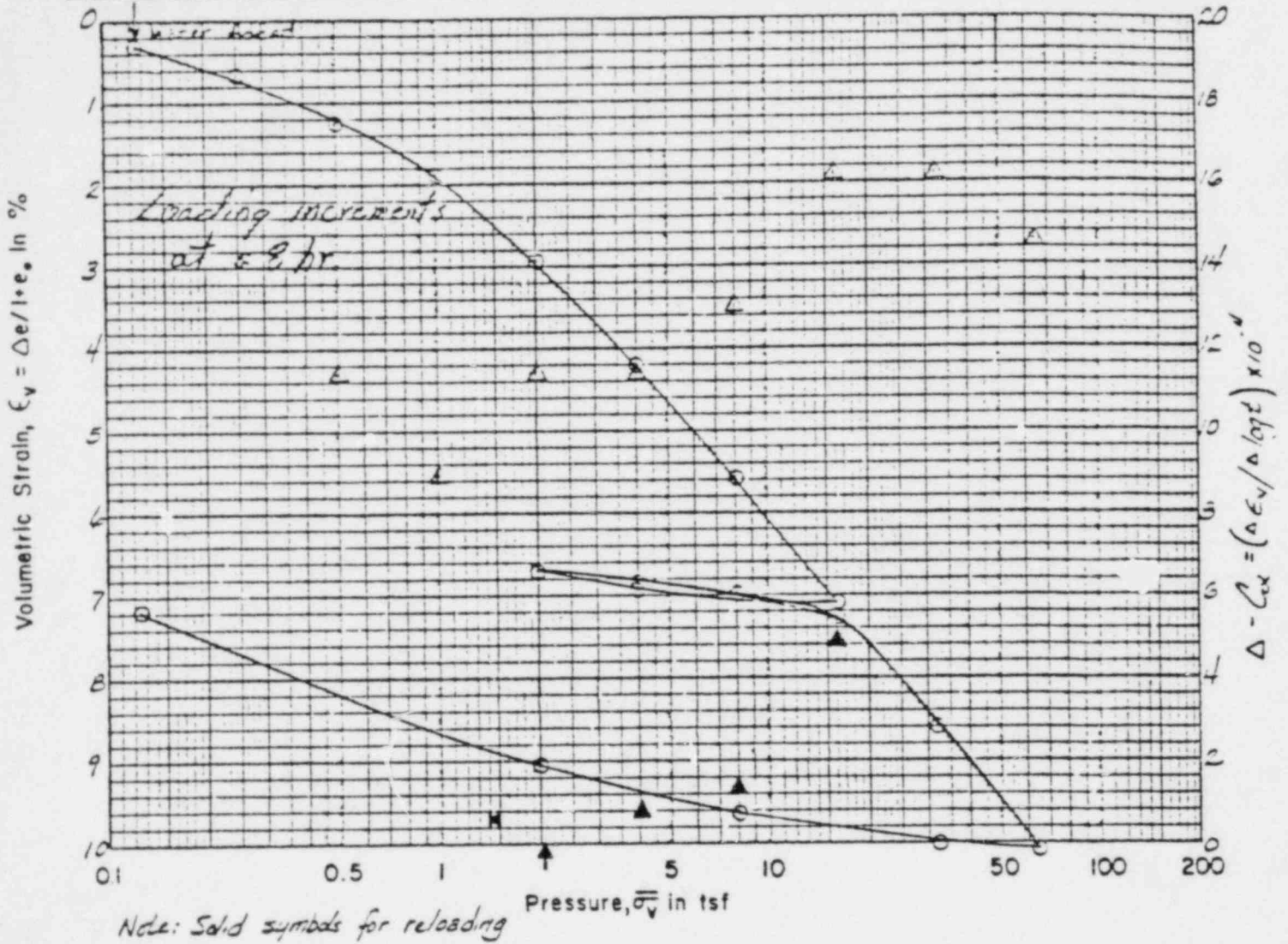
|   |                  |                        |                 |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No. CDE-13A  |                  |                        | Sample No. S-8B |               |                | Depth, ft. 24.4  |                  |                 |                  |
| Material. CL, mottled gr-br. & cr-br. m to s. sandy s.p. silty CLAY, tr. & gravel to c sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 10.7             | 141.3                  | 0.340           | 86.4          | 0.613          | 2.50             | 2.744            | 21              | 12               |
| Final   | 10.4             | 144.7                  | 0.304           | 93.7          | 0.597          |                  |                  |                 |                  |



Note: Solid Symbols for reloading

# CONSOLIDATION TEST

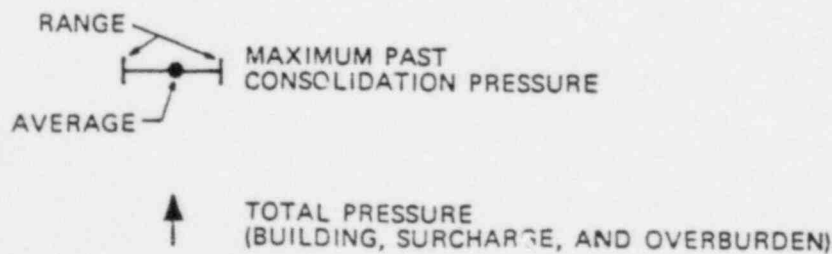
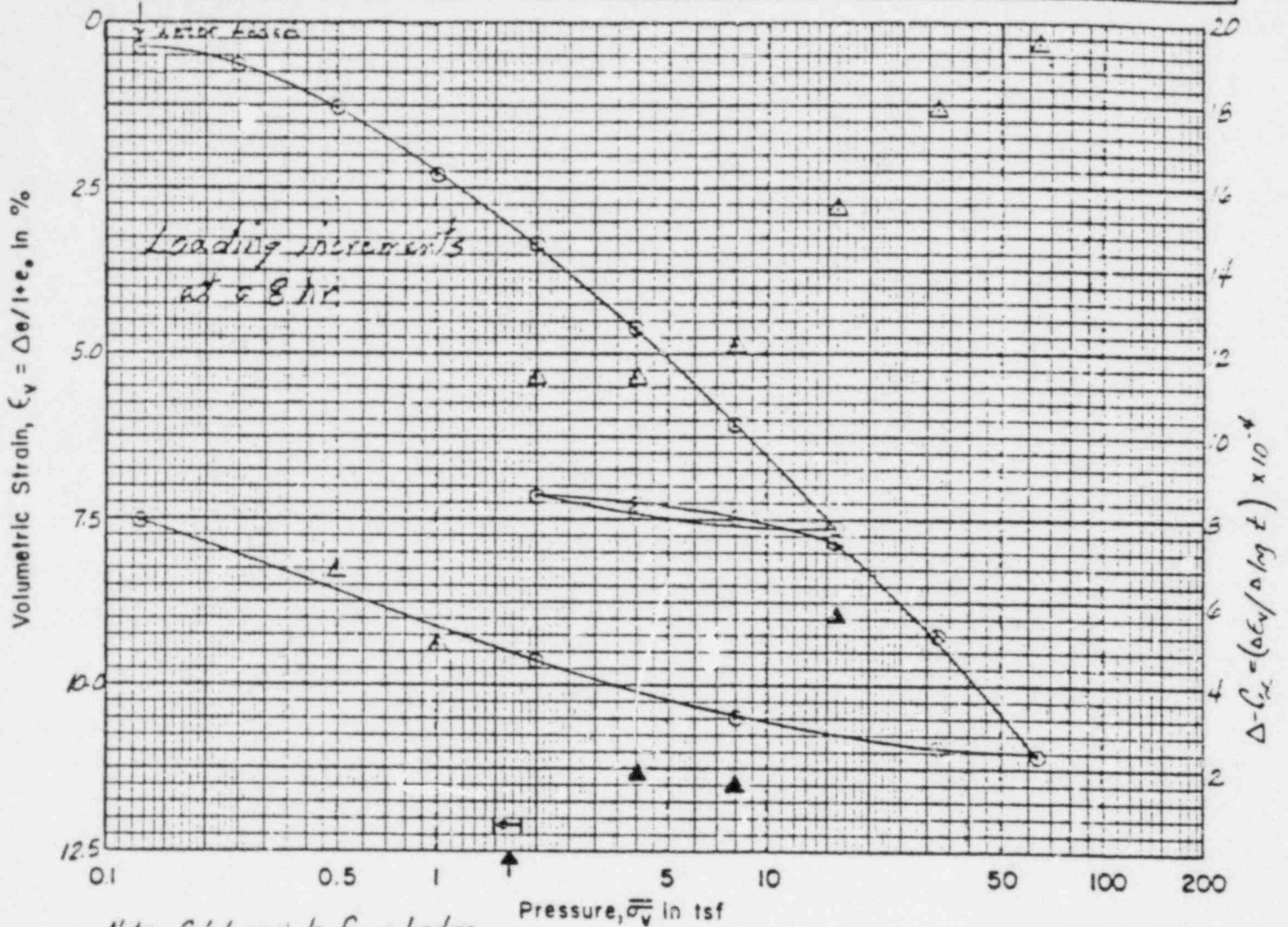
|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COF-9   |                  | Sample No: S-6C        |            |               |                | Depth, ft: 16.5  |                  |                 |                  |
| Material: CL, brown & sandy, s.p. silty CLAY, some f. gravel & m. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 11.7             | 132.2                  | 0.374      | 84.3          | 0.616          | 2.50             | 2.745            | 20              | 12               |
| Final  | 10.4             | 146.1                  | 0.292      | 97.3          | 0.560          |                  |                  |                 |                  |





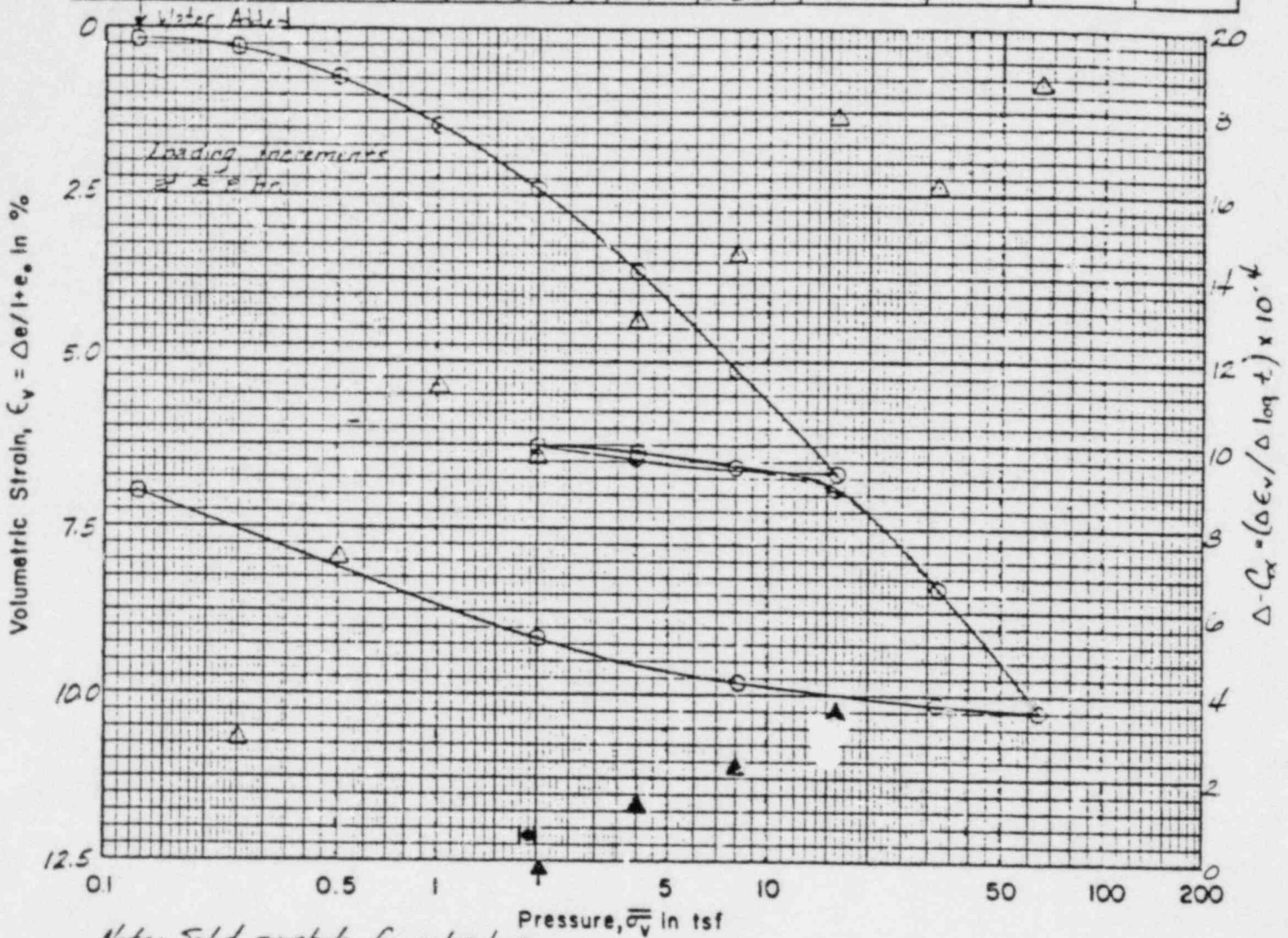
# CONSOLIDATION TEST

|  |                  |                        |            |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-9   |                  | Sample No: S-3B        |            |               |                | Depth, ft: 9.0   |                  |                 |                  |
| Material: CL, br. m to s sandy s.p. silty CLAY, trace s. gravel to c. sand |                  |                        |            |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 13.7             | 135.9                  | 0.440      | 66.1          | 0.615          | 2.50             | 2.762            | 21              | 12               |
| Final  | 13.0             | 142.1                  | 0.369      | 97.7          | 0.564          |                  |                  |                 |                  |



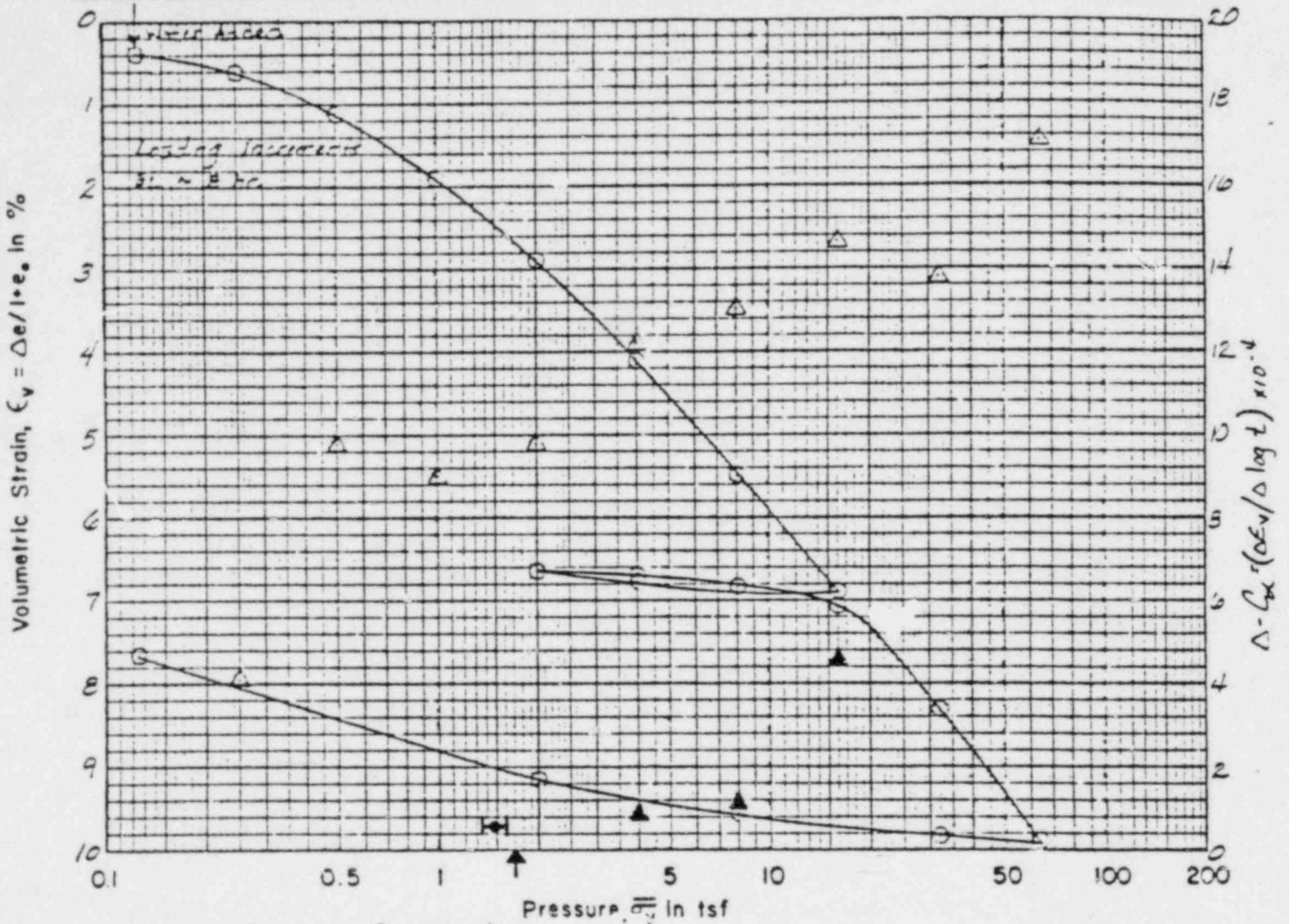
# CONSOLIDATION TEST

|   |                  |                        |            |               |                |                  |                  |                 |                  |
|---|------------------|------------------------|------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-10A  |                  | Sample No: S-2C        |            |               |                | Depth, ft: 13.6  |                  |                 |                  |
| Material: CL mottled br gr and orange-br f. sandy s.s. silty clay fr. c-r. s-r. |                  |                        |            |               |                |                  |                  |                 |                  |
|   | Water Content, % | Total Unit Weight, pcf | Void Ratio | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial   | 12.3             | 153.0                  | 0.443      | 76.4          | 0.616          | 2.50             | 2.741            | 21              | 13               |
| Final   | 12.5             | 143.0                  | 0.343      | 99.7          | 0.574          |                  |                  |                 |                  |



# CONSOLIDATION TEST

|  |                  |                        |                 |               |                |                  |                  |                 |                  |
|--|------------------|------------------------|-----------------|---------------|----------------|------------------|------------------|-----------------|------------------|
| Boring No: COE-12A   |                  |                        | Sample No: S-3C |               |                | Depth, ft: 12.1  |                  |                 |                  |
| Material: CL, mottled gray & br. S. sandy sp. silty CLAY, tr. S. gravel to m. sand |                  |                        |                 |               |                |                  |                  |                 |                  |
|  | Water Content, % | Total Unit Weight, pcf | Void Ratio      | Saturation, % | Height, inches | Diameter, inches | Specific Gravity | Liquid Limit, % | Plastic Limit, % |
| Initial  | 11.9             | 126.8                  | 0.376           | 86.7          | 0.614          | 2.50             | 2.740            | 21              | 13               |
| Final  | 10.5             | 147.1                  | 0.283           | 102.0         | 0.573          |                  |                  |                 |                  |



Note: Solid symbols for reloading

ENCLOSURE 2

Dr R B Peck's Evaluation of the Boring Results



SUBJECT: DIESEL GENERATOR BUILDING: CONSOLIDATION TESTS

In accordance with your request I have reviewed the report by Woodward-Clyde Consultants dated 22 July 1981 and entitled, "Estimates of Maximum Past Consolidation Pressure of Cohesive Fill Materials, Diesel Generator Building, Midland Project - Units 1 and 2, Midland, Michigan," as well as the source material contained in Woodward-Clyde's report, "Test Results, Diesel Generator Building, Soil Boring and Testing Program, Midland plants - Units 1 and 2, Midland, Michigan," dated 8 July 1981. This letter constitutes my evaluation of the significance of the results of this program with respect to the efficacy of the surcharge program in consolidating the plant fill beneath the Diesel Generator Building.

The program was carried out by Woodward-Clyde Consultants during the period 13 March through 7 July 1981. Borings were made in accordance with a carefully planned and executed program and tests were carried out according to the best engineering practice. Although I did not observe the boring, sampling or testing, I have no reason to believe that the work was not expertly done, fully in accord with the best state of the art. In addition to carrying out consolidation tests, Woodward-Clyde Consultants were requested to determine the preconsolidation pressure corresponding to each of the consolidation tests by means of the customary Casagrande procedure. (See the attached two pages from the original paper describing the procedure). This was done by three different engineers familiar with the techniques but unfamiliar with the surcharge history and stress conditions at the Diesel Generator Building. Thus, the results of these determinations can, in my judgement, be considered representative of apparent preconsolidation pressures that would be determined by experienced and well trained practitioners. The results are presented in the report dated 22 July 1981, together with a summary of the pertinent properties of the materials for the various tests and a description of the manner in which the estimates were made. The estimates are presented in Figure 4 of the report of 22 July.

In order to define the slope of the steeper second branch (or virgin branch) of the e-log p curves, Woodward-Clyde carried the maximum consolidation pressures to values of 64 tons per square foot. This permitted developing a rebound curve by unloading and reloading the samples at an intermediate stage of the tests. The unloading-reloading curves were obtained because they are useful in some of the procedures for evaluating the preconsolidation pressure. The values of preconsolidation pressure given in Woodward-Clyde's Figure 4 are based on tests carried out to the full 64 tons per square foot.

Moreover, a series of consolidation tests had been carried out by Goldberg-Zoino-Dunncliff on borings made in 1978, before surcharging. These tests provided an opportunity for a comparison of apparent preconsolidation pressures, as determined from the tests, before and after surcharging. The GZD tests were carried to a maximum pressure, however, of only 16 tons per square foot. Therefore, the apparent preconsolidation pressures determined on the GZD samples by the Woodward-Clyde personnel were necessarily based on maximum test pressures of 16 tons per square foot. For the comparison with the Woodward-Clyde samples taken after surcharging, the preconsolidation pressures for the Woodward-Clyde samples were also evaluated as if the tests

had not extended beyond pressures of 16 tons per square foot. Hence, although the latter estimates are not the best possible ones for the Diesel Generator Building after surcharging (the best values are shown in Figure 4), they are the appropriate ones for comparison with the pre-surge values. This comparison is shown in Figure 3 of the report of 22 July.

The comparison of apparent preconsolidation pressure on the GZD samples taken before surcharging and the WCCO samples taken afterwards shown in WCCO Figure 3, clearly indicates a gain in preconsolidation pressures as a consequence of surcharging. Nevertheless, the inevitable scatter of results precludes definite conclusions regarding the magnitude of the increase.

A review of the results of the individual consolidation tests, summarized in WCCO's report of 22 July 1981, demonstrates that all the strain-log pressure curves are smooth curves, without obvious breaks between a flatter upper and a steeper lower branch. Therefore, choice of the point on the curve representing the maximum curvature or minimum radius of curvature, a point that must be determined to carry out the Casagrande construction, leaves wide margin for interpretation. The summary plot, Figure 4, shows the average value and also the range of preconsolidation pressures estimated for each test by the three engineers.

The values of apparent preconsolidation pressures estimated by the three Woodward-Clyde engineers and plotted in their composite diagram, Figure 4, are replotted on the attached diagram for each of the five borings. In addition, for each boring, the calculated stresses due to the loading during the surcharge period are plotted as smooth curves. Thus, for each boring, the apparent preconsolidation pressures of the tested samples can be compared directly with the pressures during surcharging. It is evident that some values of the apparent consolidation pressure are lower and some higher than the pressures known to have been acting during the surcharge. In my judgement, the observed degree of scatter of the results is not unusual and is inherent in the processes of boring, sampling, testing and calculation of the apparent preconsolidation pressure. Apparent preconsolidation pressures less than the pressures during surcharging do not justify the conclusion that the plant fill was not fully consolidated under the surcharge.

The foregoing statement is illustrated by following discussion. Three samples were tested from Boring COE-12A. These were at el. 623.8, 621.5 and 616.7. The average preconsolidation pressures derived from the tests were 2.27, 1.47 and 2.55 tons per square foot. These samples represented the soil in a vertical column about seven feet high. The shallowest and the deepest samples gave preconsolidation pressures appreciably higher than the intermediate sample. In reality, the preconsolidation pressure must have been nearly identical at all three points, unless the fill was extremely heterogeneous. The latter conclusion is not born out by the detailed log of Boring 12A. Therefore, one must conclude that the preconsolidation pressure determined for the sample at intermediate depth is too low. The most conservative interpretation would place the preconsolidation pressure for the intermediate sample at a value greater than 2.1 tons per square foot, the least value estimated by any of the three engineers for the overlying sample.

The inferred preconsolidation pressure as plotted by WCCO in their Figure 4 include five values from Boring 9 (3B, 4A, 5B, 6B, and 6C) that are relatively low with respect to the known surcharge stresses. One might infer from these values that the corresponding soils had not achieved one hundred percent consolidation under the surcharge loading. However, the verbal descriptions of the materials according to the boring logs range from stiff to very stiff and hard. The corresponding undrained shear strengths would then be on the order of 0.5 to more than 4 tons per square foot. Furthermore, pocket penetration tests carried out on the samples indicated equivalent unconfined compressive strengths ranging from 1.1 to 2.2 tons per square foot or undrained shear strengths from 0.55 to 1.1 tons per square foot. Hence, it is reasonable to infer that the materials displayed undrained shear strengths not less than 0.5 tons per square foot. It is known that an excellent correlation exists for normally loaded clays (that is, clays that are not overconsolidated) between the pressure under which the clays have been consolidated and the plasticity index  $I_p$ . The correlation is expressed by the equation:

$$\frac{c}{p_n} = 0.10 + 0.004 I_p$$

(See Peck, Hanson and Thornburn, Foundation Engineering, Second Edition, Page 93). The plasticity index for the five samples under discussion from Boring 9 ranges between 8 and 9 percent. The corresponding value of the ratio of shear strength  $c$  to consolidation pressure  $p_n$  ranges from 0.13 to 0.14. For a shear strength of 0.5 ton per square foot, the least value inferred from the foregoing information, the value of consolidation pressure would be computed as  $0.5/0.13$ , or 3.8 tons per square foot. This is larger than any of the apparent consolidation pressures reported and, indeed, is substantially larger than the known applied consolidation pressure.

If the converse of the foregoing empirical relation is considered, it can be calculated that the value of the ratio of undrained shear strength to consolidation pressure for a plasticity index of eight is 0.13 and the corresponding value of undrained shear strength for a consolidation pressure of 2 tons per square foot is 0.26 ton per square foot. The corresponding unconfined compressive strength, equal to twice the undrained shear strength, would be 0.52 ton per square foot, on the borderline between medium and soft clay. No description of the samples obtained in the program and no values of pocket penetrometer readings, indicated clays of such a soft consistency. Therefore, it can be concluded that the actual preconsolidation pressures for the surcharged clays of Boring 9 were substantially greater than those determined by means of sampling and testing.

Finally, it is noteworthy that although some of the apparent preconsolidation pressures derived from the tests on samples from the plant fill are lower than the known applied pressures during the period of surcharging, a greater number are substantially higher. In particular in the lower part of the fill where induced stresses due to the dewatering system will be greatest, the excess of the apparent preconsolidation pressures above the pressures during surcharging is strikingly large.

It is evident that, with the best of techniques for sampling and testing, and with interpretations carried out in accordance with the state of the art, the inferred preconsolidation pressures leave much room for interpretation and do not constitute conclusive evidence regarding the actual effectiveness of the surcharge program, which was amply demonstrated by the settlement and pore-pressure observations carried out during and after the program.



computations, and finally  $\tan^4(45 + \phi/2)$  which determines the ultimate bearing capacity for surface loading.

|                            | $\tan \phi$ | Relative Change | $\tan^2(45 - \frac{\phi}{2})$ | Relative Change | $\tan^4(45 + \frac{\phi}{2})$ | Relative Change |
|----------------------------|-------------|-----------------|-------------------------------|-----------------|-------------------------------|-----------------|
| $\phi_{\min} = 29^\circ$   | 0.554       | 1.0             | 0.347                         | 2.2             | 8.35                          | 1.0             |
| $\phi_{\max} = 46.5^\circ$ | 1.053       | 1.9             | 0.159                         | 1.0             | 39.7                          | 4.7             |

In view of such variations and uncertainties one can well sympathize with the statement by Mr. Lazarus White in his Discussion D-31.

However, the angle of internal friction is not the only factor which determines the stability of a mass of soil when it is subject to saturation. Let us consider the volume changes which take place during a shearing test. A fine loose sand undergoes a reduction in volume when subjected to shear, Fig. 2, while the same sand in its densest state expands during shear, Fig. 3. When the voids of the sands are completely filled with water then the volume changes during shear cause in the loose sand the squeezing out of water and in the dense sand the inflow of additional water. Since in a very large mass, time is required for flow of water to take place, secondary stresses are introduced in the soil. If the volume has the tendency to decrease, delayed drainage results in a transfer of the stresses from the solid to the water. In the case of an expanding mass the reverse takes place, that is additional pressure is set up in the solid portion. In the loose state the shearing resistance of the mass is reduced during the process of deformation and in the dense state it is increased.

That the reduction in shearing resistance of a loose saturated fill can cause entire loss of stability and flow slides, is amply demonstrated by experience. Professor Terzaghi was the first one to analyze the mechanics of these slides and he has described many examples in his publications. The fact that a mass of sand in a loose state when exposed to saturation, may be in an unstable condition, liable to flow out when a disturbance like an earth quake, occurs, has so far not been considered in earth dam design. And yet it is of utmost importance, particularly where the construction material consists largely of fine sands. In such a case a safe dam can only be built by compacting the material into a sufficiently dense state, so that any deformation will produce expansion. I wish to emphasize that safety against such internal loss of stability cannot be increased by flatter slopes. It is entirely feasible to make a fill of fine sand stable with slopes of 1 on 2, when sufficiently dense, and on the other hand, a fill of the same sand in a loose state with slopes of 1 on 5 may lose its stability and flow out. (See the writer's paper on "Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Fills," Journal Boston Soc. Civ. Eng. Jan., 1936).

Acknowledgment: The investigations, of which paper D-13 and this are progress reports, are greatly aided by the co-operation of the Committee on Earths and Foundations of the American Society of Civil Engineers, and by the Metropolitan District Water Supply Commission of Greater Boston.

No. D-34

#### DISCUSSION (By Letter)

##### THE DETERMINATION OF THE PRE-CONSOLIDATION LOAD AND ITS PRACTICAL SIGNIFICANCE

Dr. Arthur Casagrande, Graduate School of Engineering, Harvard University, Cambridge, Mass.

In reply to numerous questions on this subject which were addressed to the writer from Members of the Conference, the following notes were written.

Determination of the Pre-Consolidation Load. Professor Terzaghi's early investigations on the mechanics of consolidation of fine-grained soils led him to the conclusion that the relationship between void ratio and pressure for the primary or virgin branch of the compression curve could be expressed by a logarithmic curve. Extensive testing of undisturbed clay samples during the past five years have shown that such a logarithmic relation holds true at least up to 20 kg/sq cm, that is for the entire load range in which the civil engineer is interested. Any important deviations from the virgin compression curve of an undisturbed clay sample seem to be caused by the variations in loading which the soil underwent during its geologic history and by its removal from the ground. The reason for this can be understood from the shape of a rebound and re-compression curve obtained by loading a sample in increments well beyond the stress under which it was consolidated in the ground, then decreasing the load to zero and again gradually increasing it to an even larger load. The compression diagram for such a test is shown in Fig. 1. The left diagram is plotted to an arithmetic scale and in the diagram to the right the pressures are plotted on a logarithmic scale. The semi-log plot lends itself readily to an analysis of the history of the sample. The first portion (II) of the compression curve is in reality a re-compression curve which meets the virgin branch ( $I_b$ ) and then continues along that branch as a straight line. At the arbitrary load, corresponding to point A, the load is again reduced in the same increments to zero, whereby a rebound curve (III) is obtained. The renewed application of the load follows the re-compression curve (IV) which meets the virgin branch ( $I_b$ ) at a load higher than point A, to continue along that line.

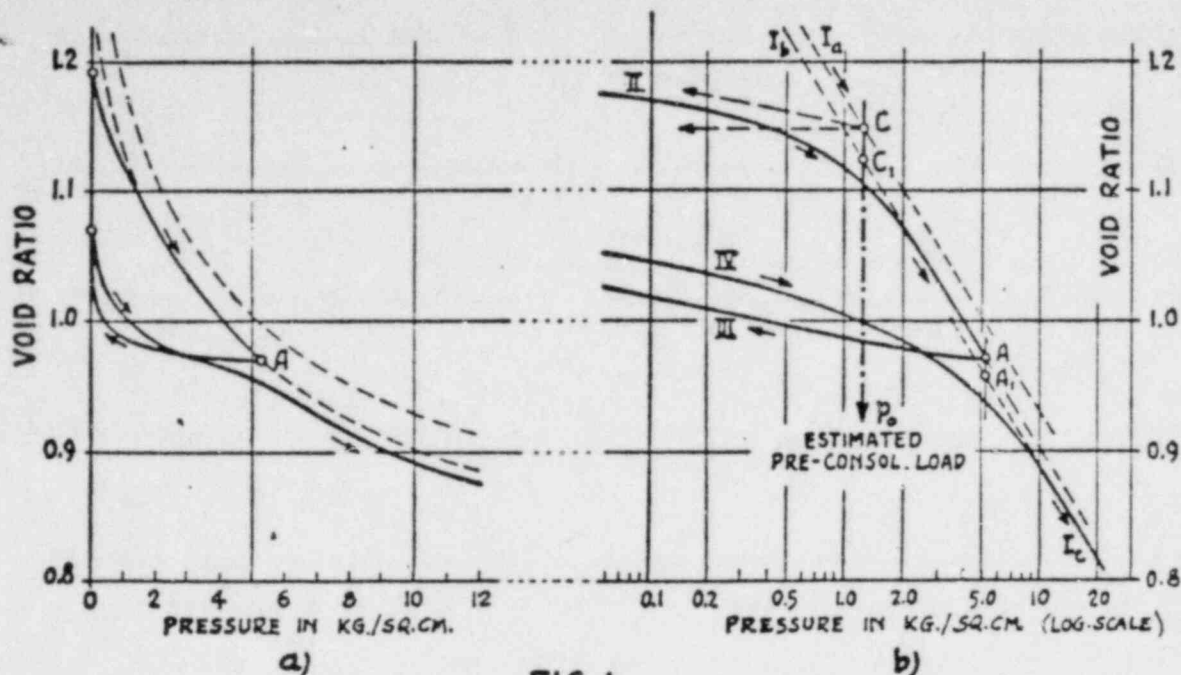


FIG. 1

The diagram shown in Fig. 1b is typical for all very fine-grained soils. The magnitude of the drop in the position of the virgin branch after each rebound loop depends chiefly on the structural characteristics of the soil. For many glacial clays this drop is very small. The exact position of the virgin branch obtained from a laboratory test, depends also on the time-increments which were allowed for each load-increment, and on the temperature.

The close similarity in the shape of branch (II) and the relative position of branch (II) and ( $I_b$ ), with the shape of the recompression curve (IV) and the relative position of (IV) and ( $I_b$ ), suggests that it should be possible to estimate the load  $p_0$  under which the soil was consolidated in the ground, the so-called pre-consolidation load, from a properly conducted consolidation test. Since the theoretical shape of the rebound and recompression curves is not sufficiently investigated, such estimates must be based on experience. From a large number of tests on different types of soils it was found that for the majority of clays the pre-consolidation load can be derived with a satisfactory degree of accuracy by means of the empirical method shown in Fig. 2. One determines first the

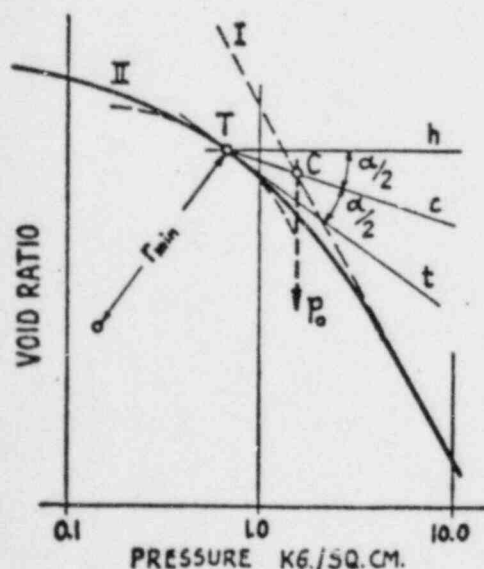
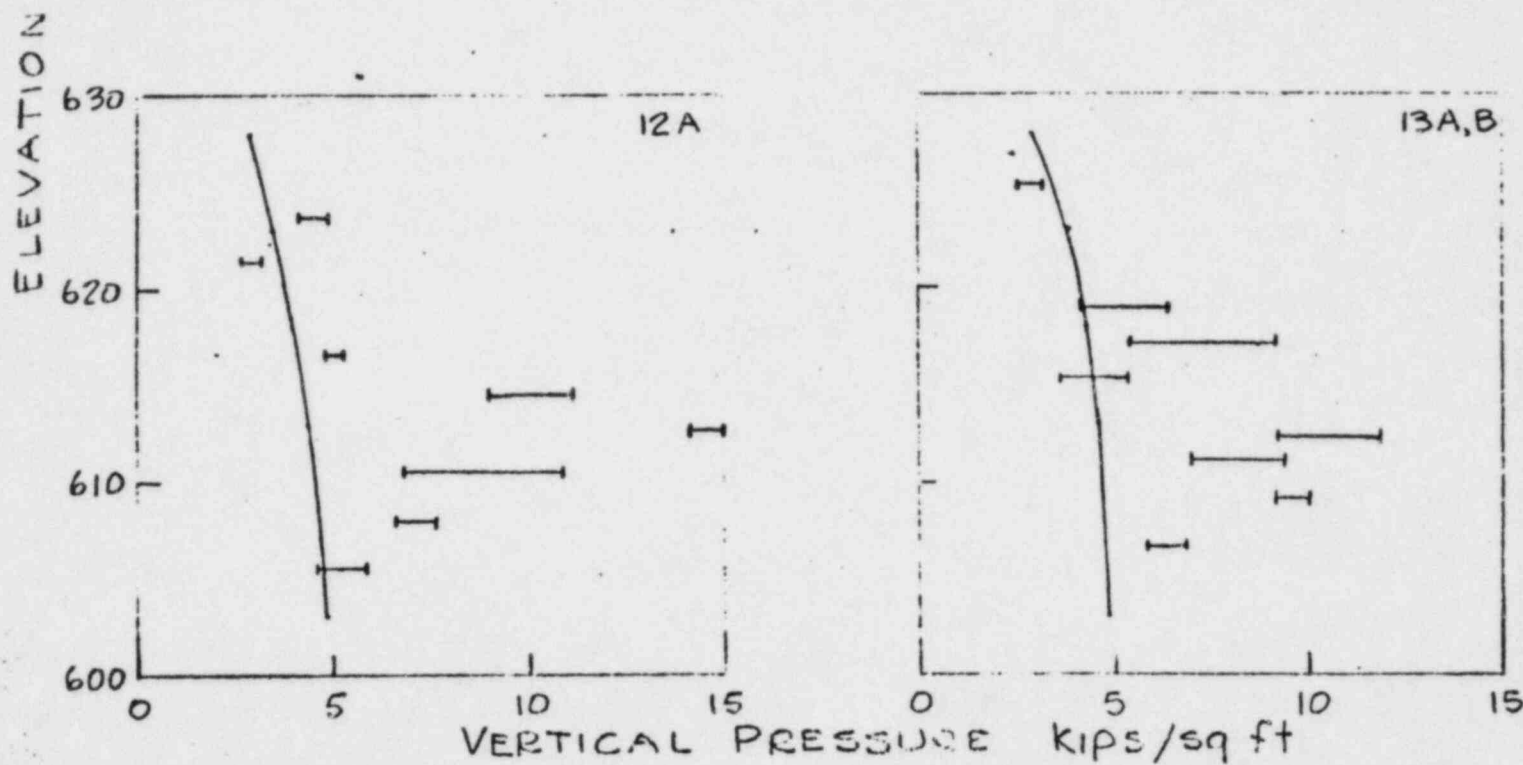
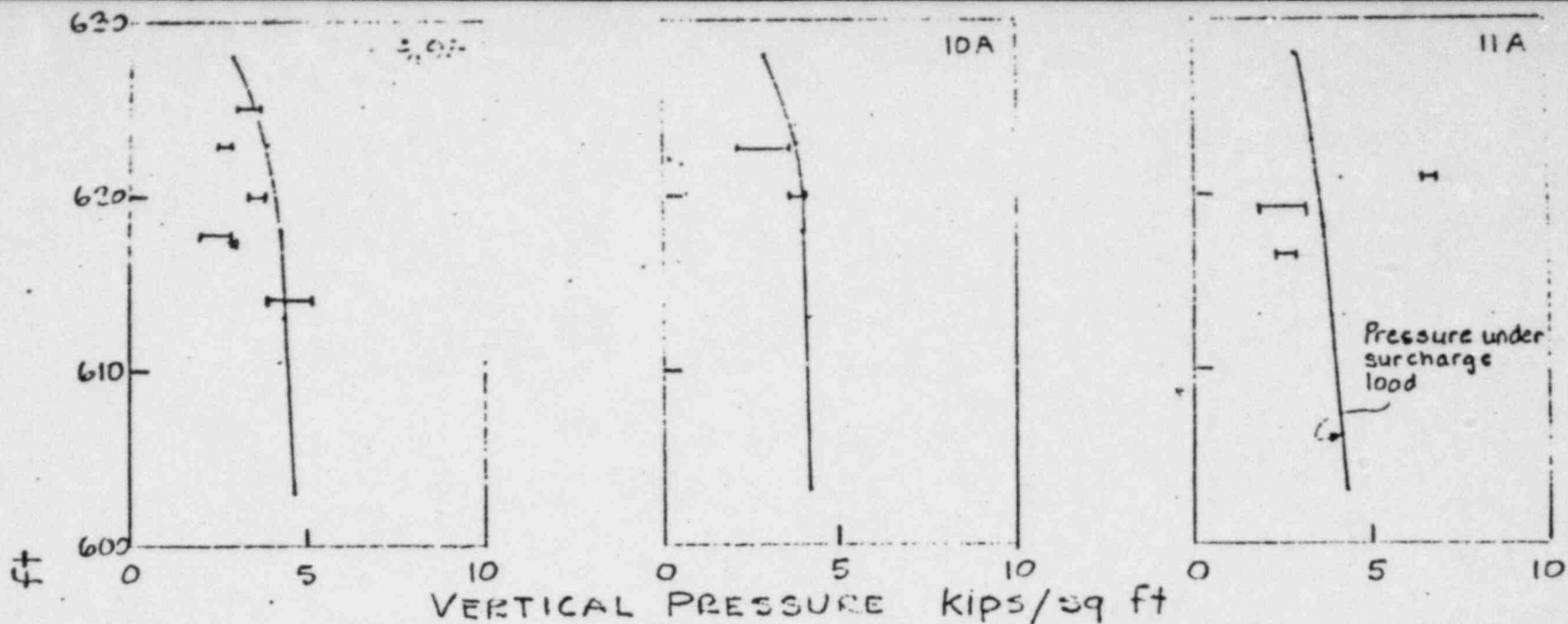


FIG. 2

position of the virgin compression line (I) with a sufficient number of points. Then one determines on the preceding branch (II) that point (T) which corresponds to the smallest radius of curvature, and draws through this point a tangent (t) to the curve, and a horizontal line (h). The angle  $\alpha$  between these two lines is then bisected, and the point of intersection (C) of this bisecting line (c) with the virgin line (I) determined. Point (C) corresponds approximately to the pre-consolidation load ( $p_0$ ) of the soil in the ground.

The question immediately arises whether the drop in the position of the virgin compression line, due to the temporary removal of the load and the inevitable deformation of the sample during its removal from the ground and preparation for the test, affects the magnitude of the estimated pre-consolidation load. So far, experience seems to indicate that this is not the case. In other words, the partial break-down in the internal structure of the soil, due to a small amount of deformation, or alternate swelling and compression, does not obliterate or seriously distort the impression created in the material by the largest previous load.

Theoretical considerations, based on the writer's hypothesis of the structure of clays (Journal of the Boston Soc. of Civ. Eng., April 1932), lead to the same conclusion. The slight increase in compressibility is probably due to the breakdown of a small percentage of soil arches. However, in the major portion of the soil the structure is still intact and, therefore, the impression produced by the pre-consolidation load can be assumed to be unchanged.



DGB

COMPARISON OF  
WCC MAXIMUM  
PAST CONSOLIDA-  
TION PRESSURE  
AND  
PRESSURE UNDER  
SURCHARGE LOAD

— Range of values of  
preconsolidation pres-  
sure by WCC.