

# THE CORRELATION OF RIVET STRENGTH WITH HARDNESS MEASUREMENTS

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# Presentation Outline

- ◎ Background
- ◎ History
- ◎ Experimental study
- ◎ Results
- ◎ Future work



# Hardness

## ⦿ Rockwell Hardness

- Depth of penetration of indenter under a large load compared to the penetration made by a preload

## ⦿ ASTM A370

- Estimates ultimate tensile strength

## ⦿ Equipment

- Laboratory
- Portable

# Hardness Testing Devices

## ● Benchtop



## ● Portable



# Rivet Hardness Correlation



A370 - 09a<sup>1</sup>

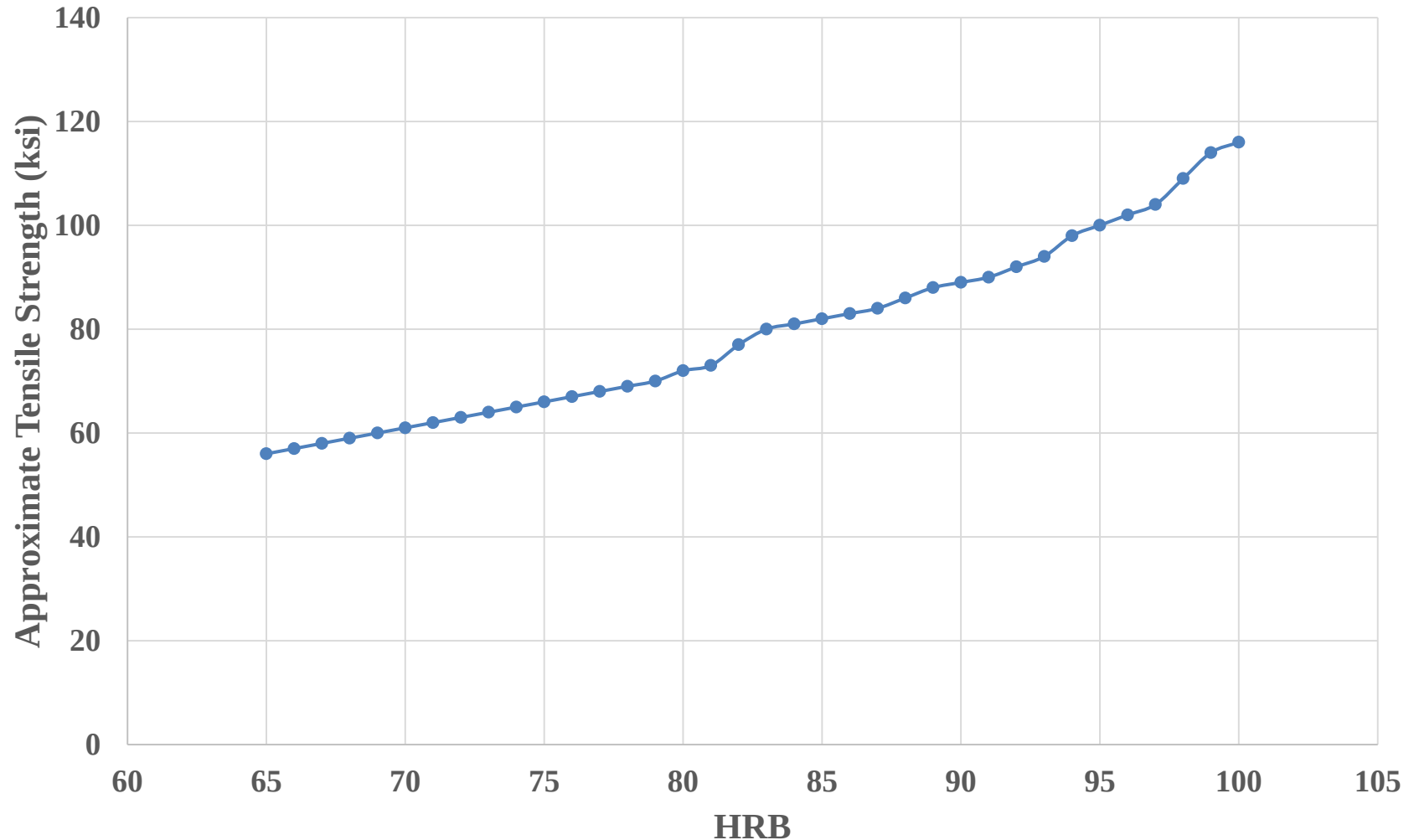
TABLE 3 Approximate Hardness Conversion Numbers for Non-austenitic Steels<sup>a</sup> (Rockwell B to Other Hardness Numbers)

| Rockwell B<br>Scale, 100-<br>kgf Load 1/16-<br>in. (1.588-<br>mm) Ball | Vickers<br>Hardness<br>Number | Brinell<br>Hardness,<br>3000-kgf Load,<br>10-mm Ball | Knoop<br>Hardness,<br>500-gf Load<br>and Over | Rockwell A<br>Scale,<br>60-kgf<br>Load, Diamond<br>Penetrator | Rockwell F<br>Scale,<br>60-kgf<br>Load, 1/16-in.<br>(1.588-mm) Ball | Rockwell Superficial Hardness                                    |                                                                  |                                                                  | Approximate<br>Tensile<br>Strength<br>ksi (MPa) |
|------------------------------------------------------------------------|-------------------------------|------------------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------|
|                                                                        |                               |                                                      |                                               |                                                               |                                                                     | 15T Scale,<br>15-kgf<br>Load,<br>1/16-in.<br>(1.588-<br>mm) Ball | 30T Scale,<br>30-kgf<br>Load,<br>1/16-in.<br>(1.588-<br>mm) Ball | 45T Scale,<br>45-kgf<br>Load,<br>1/16-in.<br>(1.588-<br>mm) Ball |                                                 |
| 100                                                                    | 240                           | 240                                                  | 251                                           | 61.5                                                          | ...                                                                 | 93.1                                                             | 83.1                                                             | 72.9                                                             | 116 (800)                                       |
| 99                                                                     | 234                           | 234                                                  | 246                                           | 60.9                                                          | ...                                                                 | 92.9                                                             | 82.5                                                             | 71.9                                                             | 114 (785)                                       |
| 98                                                                     | 228                           | 228                                                  | 241                                           | 60.2                                                          | ...                                                                 | 92.5                                                             | 81.8                                                             | 70.9                                                             | 109 (750)                                       |
| 97                                                                     | 222                           | 222                                                  | 236                                           | 59.5                                                          | ...                                                                 | 92.1                                                             | 81.1                                                             | 69.9                                                             | 104 (715)                                       |
| 96                                                                     | 216                           | 216                                                  | 231                                           | 58.9                                                          | ...                                                                 | 91.8                                                             | 80.4                                                             | 68.9                                                             | 102 (705)                                       |
| 95                                                                     | 210                           | 210                                                  | 226                                           | 58.3                                                          | ...                                                                 | 91.5                                                             | 79.8                                                             | 67.9                                                             | 100 (690)                                       |
| 94                                                                     | 204                           | 204                                                  | 221                                           | 57.7                                                          | ...                                                                 | 91.1                                                             | 79.1                                                             | 67.1                                                             | 98 (675)                                        |
| 93                                                                     | 198                           | 198                                                  | 216                                           | 57.1                                                          | ...                                                                 | 90.7                                                             | 78.4                                                             | 66.4                                                             | 96 (665)                                        |
| 92                                                                     | 195                           | 195                                                  | 211                                           | 56.4                                                          | ...                                                                 | 90.5                                                             | 77.8                                                             | 64.8                                                             | 92 (635)                                        |
| 91                                                                     | 190                           | 190                                                  | 206                                           | 55.8                                                          | ...                                                                 | 90.2                                                             | 77.1                                                             | 63.8                                                             | 90 (620)                                        |
| 90                                                                     | 185                           | 185                                                  | 201                                           | 55.2                                                          | ...                                                                 | 89.9                                                             | 76.4                                                             | 62.8                                                             | 89 (615)                                        |
| 89                                                                     | 180                           | 180                                                  | 196                                           | 54.6                                                          | ...                                                                 | 89.5                                                             | 75.8                                                             | 61.8                                                             | 88 (605)                                        |
| 88                                                                     | 176                           | 176                                                  | 192                                           | 54.0                                                          | ...                                                                 | 89.2                                                             | 75.1                                                             | 60.8                                                             | 86 (590)                                        |
| 87                                                                     | 172                           | 172                                                  | 188                                           | 53.4                                                          | ...                                                                 | 88.9                                                             | 74.4                                                             | 59.8                                                             | 84 (580)                                        |
| 86                                                                     | 169                           | 169                                                  | 184                                           | 52.8                                                          | ...                                                                 | 88.6                                                             | 73.8                                                             | 58.8                                                             | 83 (570)                                        |
| 85                                                                     | 165                           | 165                                                  | 180                                           | 52.3                                                          | ...                                                                 | 88.2                                                             | 73.1                                                             | 57.8                                                             | 82 (565)                                        |
| 84                                                                     | 162                           | 162                                                  | 176                                           | 51.7                                                          | ...                                                                 | 87.9                                                             | 72.4                                                             | 56.8                                                             | 81 (560)                                        |
| 83                                                                     | 159                           | 159                                                  | 173                                           | 51.1                                                          | ...                                                                 | 87.6                                                             | 71.8                                                             | 55.8                                                             | 80 (550)                                        |
| 82                                                                     | 156                           | 156                                                  | 170                                           | 50.6                                                          | ...                                                                 | 87.3                                                             | 71.1                                                             | 54.8                                                             | 77 (530)                                        |
| 81                                                                     | 153                           | 153                                                  | 167                                           | 50.0                                                          | ...                                                                 | 86.9                                                             | 70.4                                                             | 53.8                                                             | 73 (505)                                        |
| 80                                                                     | 150                           | 150                                                  | 164                                           | 49.5                                                          | ...                                                                 | 86.6                                                             | 69.7                                                             | 52.8                                                             | 72 (495)                                        |
| 79                                                                     | 147                           | 147                                                  | 161                                           | 48.9                                                          | ...                                                                 | 86.3                                                             | 69.1                                                             | 51.8                                                             | 70 (485)                                        |
| 78                                                                     | 144                           | 144                                                  | 158                                           | 48.4                                                          | ...                                                                 | 86.0                                                             | 68.4                                                             | 50.8                                                             | 69 (475)                                        |
| 77                                                                     | 141                           | 141                                                  | 155                                           | 47.9                                                          | ...                                                                 | 85.6                                                             | 67.7                                                             | 49.8                                                             | 68 (470)                                        |
| 76                                                                     | 139                           | 139                                                  | 152                                           | 47.3                                                          | ...                                                                 | 85.3                                                             | 67.1                                                             | 48.8                                                             | 67 (460)                                        |
| 75                                                                     | 137                           | 137                                                  | 150                                           | 46.8                                                          | 99.6                                                                | 85.0                                                             | 66.4                                                             | 47.8                                                             | 66 (455)                                        |
| 74                                                                     | 135                           | 135                                                  | 147                                           | 46.3                                                          | 99.1                                                                | 84.7                                                             | 65.7                                                             | 46.8                                                             | 65 (450)                                        |
| 73                                                                     | 132                           | 132                                                  | 145                                           | 45.8                                                          | 98.5                                                                | 84.3                                                             | 65.1                                                             | 45.8                                                             | 64 (440)                                        |
| 72                                                                     | 130                           | 130                                                  | 143                                           | 45.3                                                          | 98.0                                                                | 84.0                                                             | 64.4                                                             | 44.8                                                             | 63 (435)                                        |
| 71                                                                     | 127                           | 127                                                  | 141                                           | 44.8                                                          | 97.4                                                                | 83.7                                                             | 63.7                                                             | 43.8                                                             | 62 (425)                                        |
| 70                                                                     | 125                           | 125                                                  | 139                                           | 44.3                                                          | 96.8                                                                | 83.4                                                             | 63.1                                                             | 42.8                                                             | 61 (420)                                        |
| 69                                                                     | 123                           | 123                                                  | 137                                           | 43.8                                                          | 96.2                                                                | 83.0                                                             | 62.4                                                             | 41.8                                                             | 60 (415)                                        |
| 68                                                                     | 121                           | 121                                                  | 135                                           | 43.3                                                          | 95.6                                                                | 82.7                                                             | 61.7                                                             | 40.8                                                             | 59 (405)                                        |
| 67                                                                     | 119                           | 119                                                  | 133                                           | 42.8                                                          | 95.1                                                                | 82.4                                                             | 61.0                                                             | 39.8                                                             | 58 (400)                                        |
| 66                                                                     | 117                           | 117                                                  | 131                                           | 42.3                                                          | 94.5                                                                | 82.1                                                             | 60.4                                                             | 38.7                                                             | 57 (395)                                        |
| 65                                                                     | 116                           | 116                                                  | 129                                           | 41.8                                                          | 93.9                                                                | 81.8                                                             | 59.7                                                             | 37.7                                                             | 56 (385)                                        |
| 64                                                                     | 114                           | 114                                                  | 127                                           | 41.4                                                          | 93.4                                                                | 81.4                                                             | 59.0                                                             | 36.7                                                             | ...                                             |

73

64 (440)

# Hardness vs Approximate Tensile Strength



# Motivation

- ⦿ Evaluation of existing structures
- ⦿ Expense of destructively removing
  - Cost of labor
  - Cost of testing
- ⦿ Rivet data is somewhat variable
  - History (i.e., age)
  - Effects of driving



# History of Rivet Material Requirements



**15**  
*Steel Design Guide Series*

***AISC Rehabilitation and Retrofit Guide***  
*A Reference for Historic Shapes and Specifications*

Roger L. Brockenbrough, PE  
R. L. Brockenbrough & Associates, Inc.  
Pittsburgh, PA

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

# History of Rivet Material Requirements

## ◎ ASTM A7 Rivet Steel

- ~1901-1931
  - 1901-1904: 50 - 60ksi
  - 1905-1913: 50 ksi desired
  - 1914-1931: 46 - 56 ksi

## ◎ ASTM A141

- 1932-1967: 52 ksi - 62 ksi
  - 1932-1933 – Tentative revision to A7

## ◎ ASTM A195: High-Strength Rivet Steel

## ◎ ASTM A406: High-Strength Structural Alloy Rivet Steel

# History of Rivet Material Requirements

## ◎ ASTM A502

- 1967-present
- 3 Grades
  - Grade 1: Carbon steel rivets
  - Grade 2: Carbon Manganese rivets
  - Grade 3: Weathering steel rivets
- No strength limits
  - Grade 1:  $55 \leq \text{HRB} \leq 72$
  - Grade 2:  $76 \leq \text{HRB} \leq 85$
  - Grade 3:  $76 \leq \text{HRB} \leq 93$

# Goal

- Determine hardness variation



# Rivets Tested

- ◎ 1890 – BNSF Bridge
- ◎ 1892 – Gauley Bridge
- ◎ 1925 – Wilson Dam Bascule Bridge
- ◎ 1929 – Milton Madison Bridge
- ◎ 1940 – CP Bridge
- ◎ 1963 – Gauley Bridge Retrofit
- ◎ 1964 – I-35W Bridge
- ◎ 2013 – TPF-5(253) Research
- ◎ 2015 – Undriven Rivets: JayCee Rivet Supply

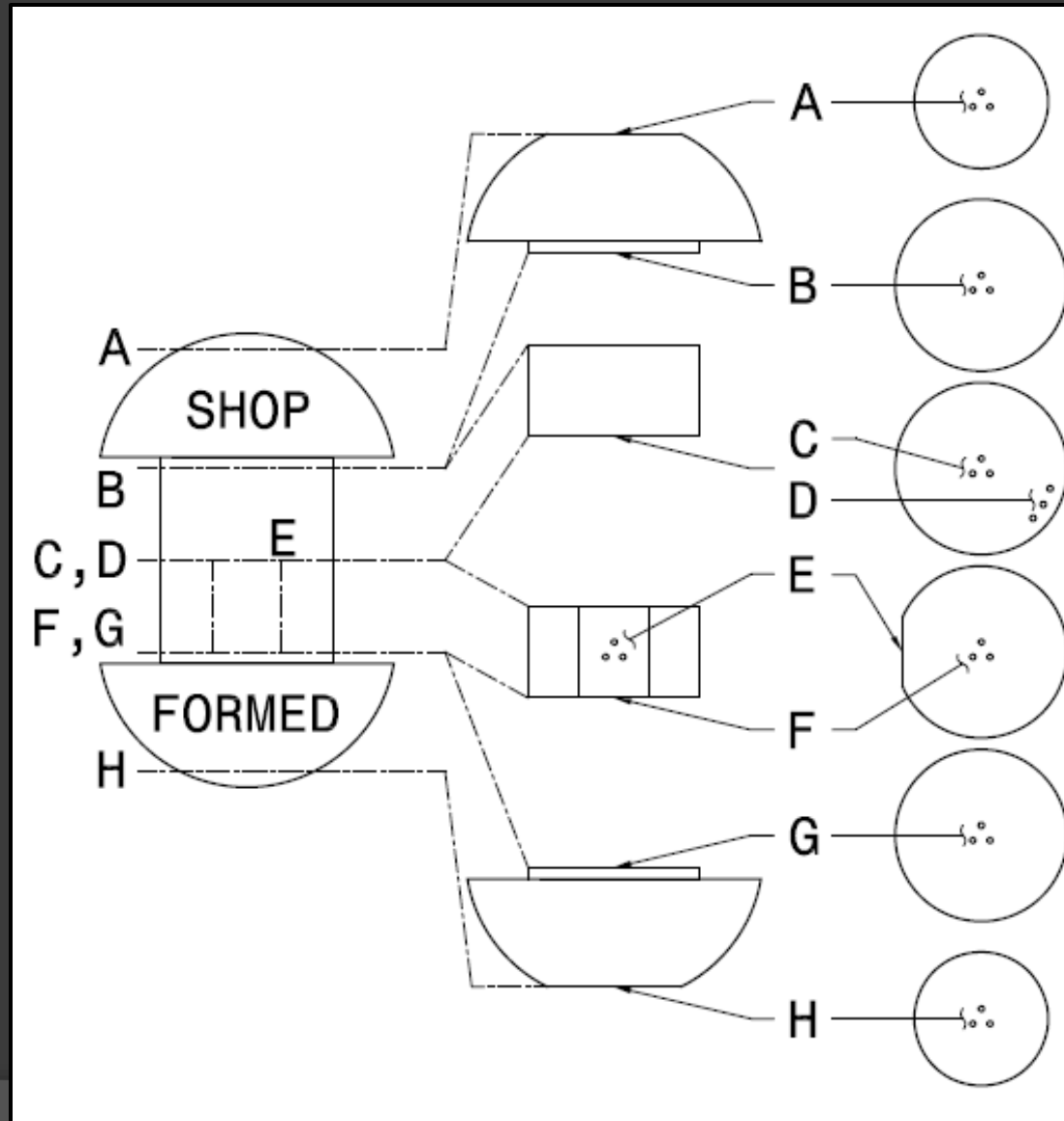
# Rivet Removal: Chipping



# Rivet Removal: Coring



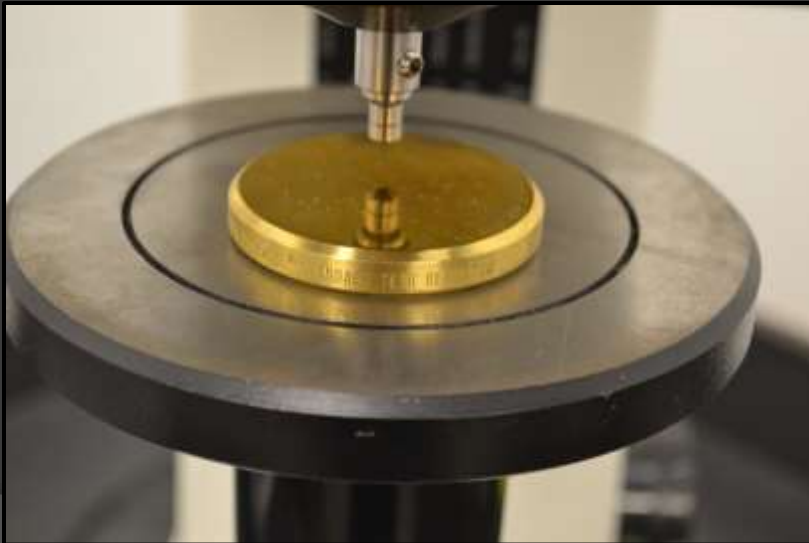
# Test Locations



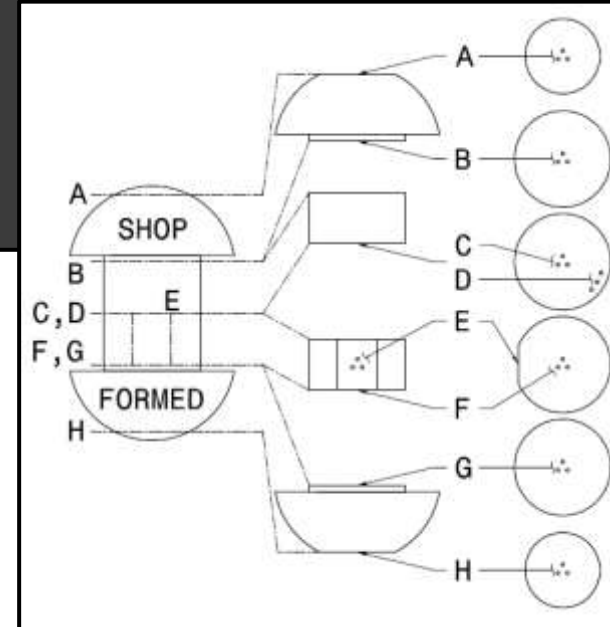
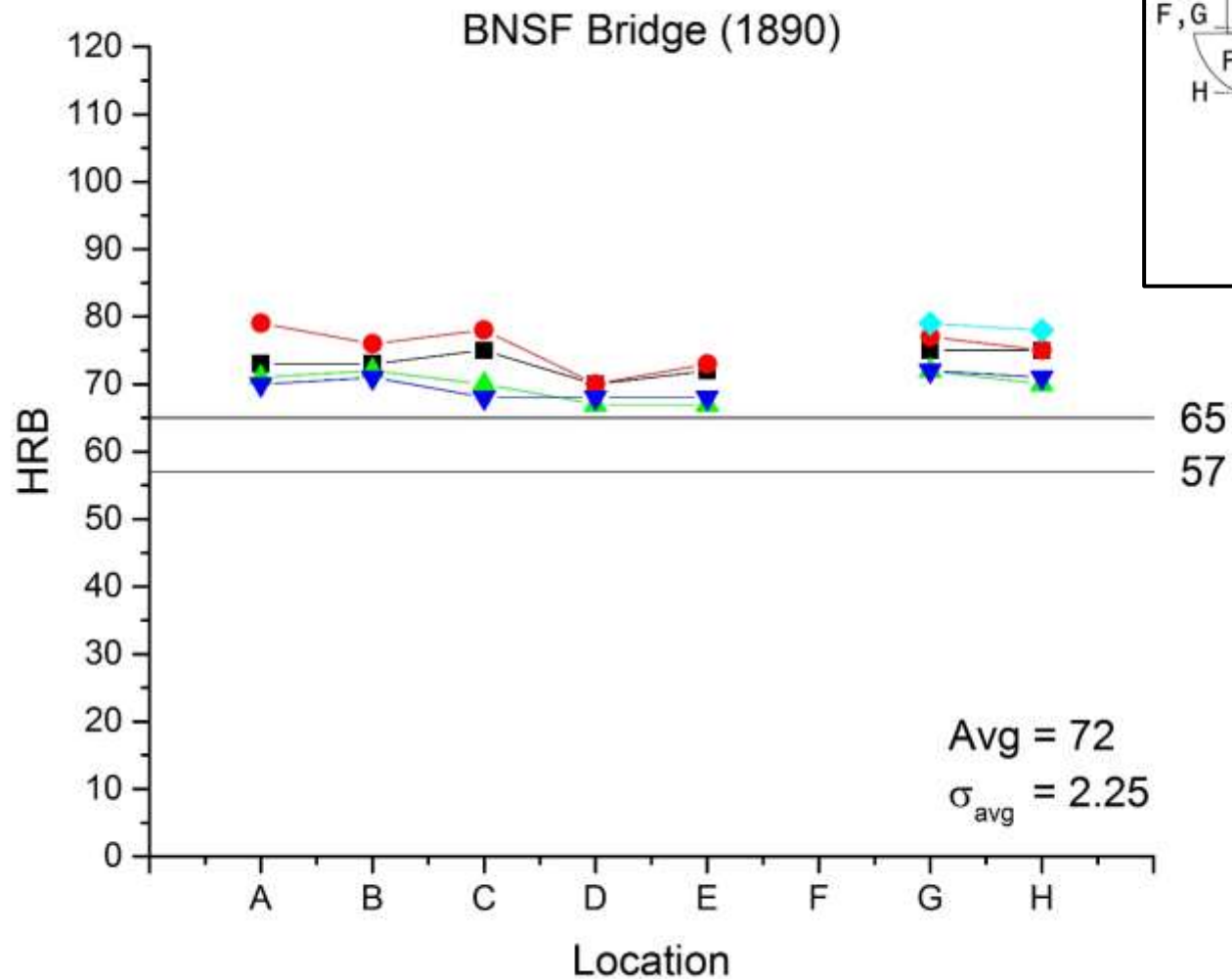
# Polishing



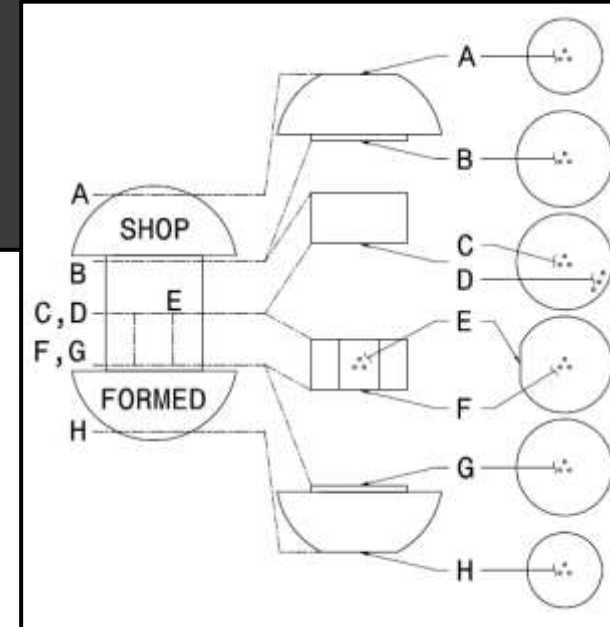
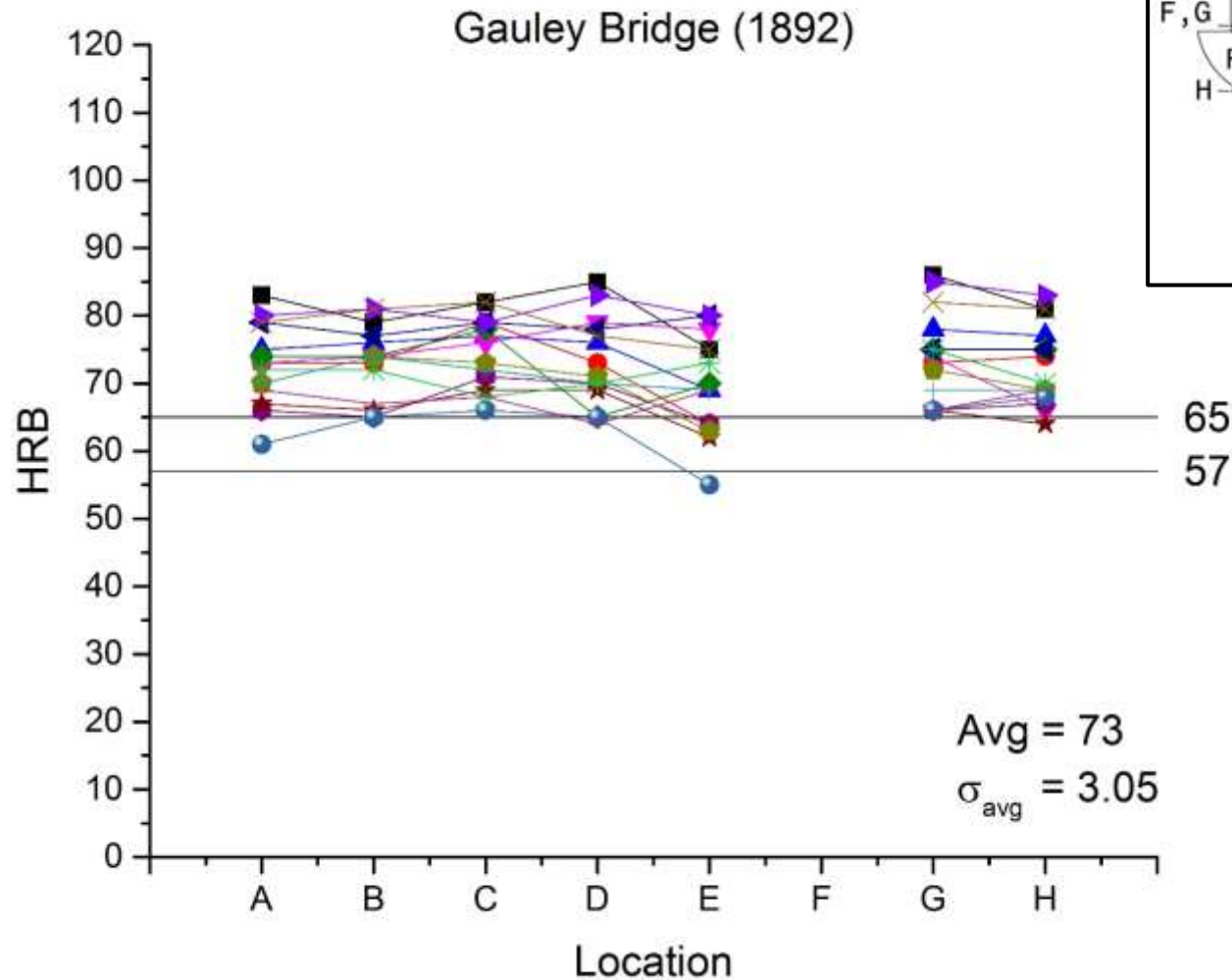
# Hardness Measurement



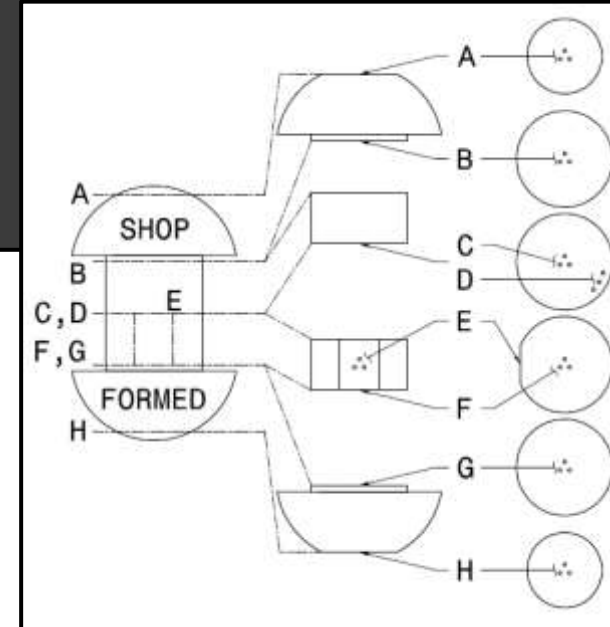
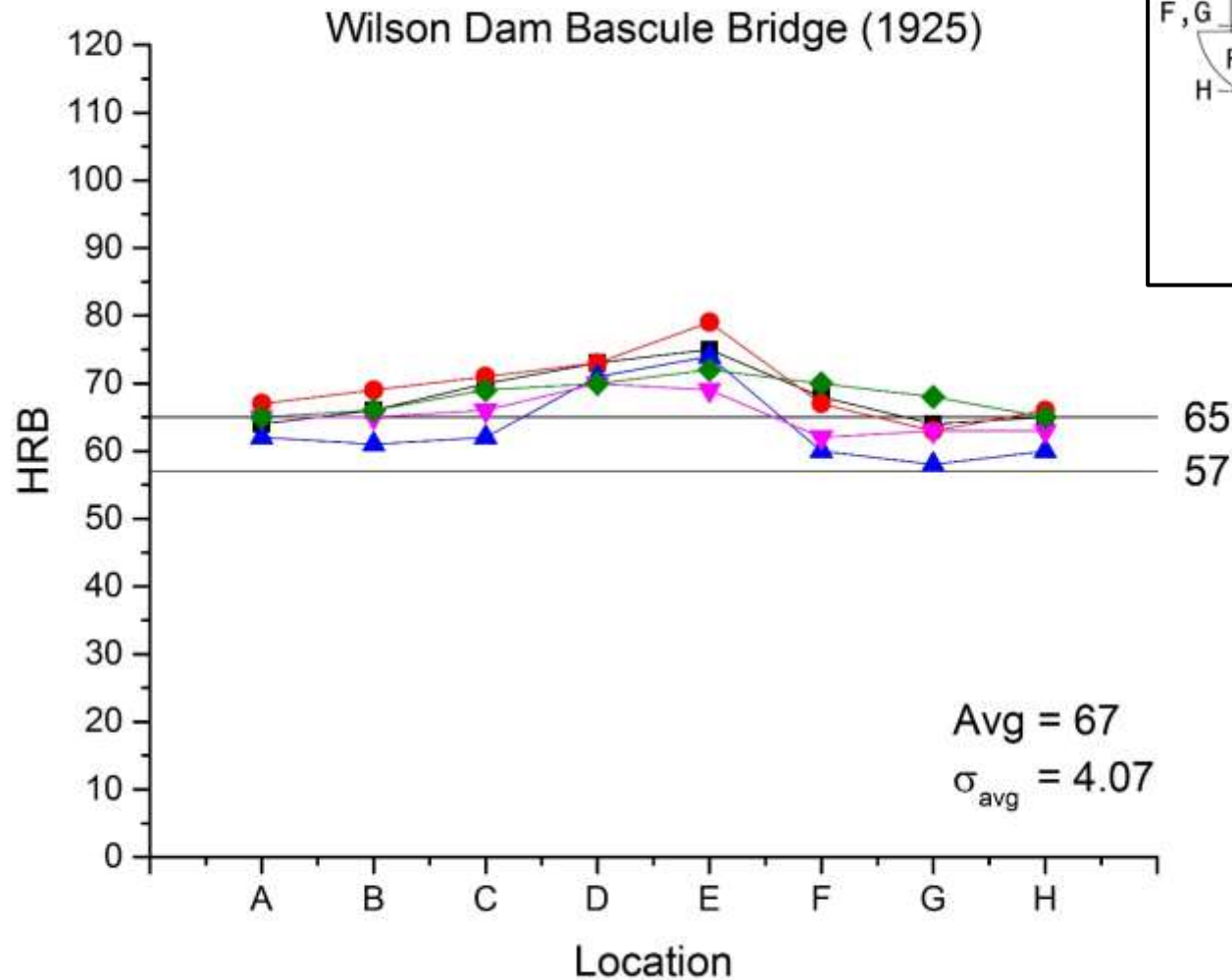
# Hardness Data



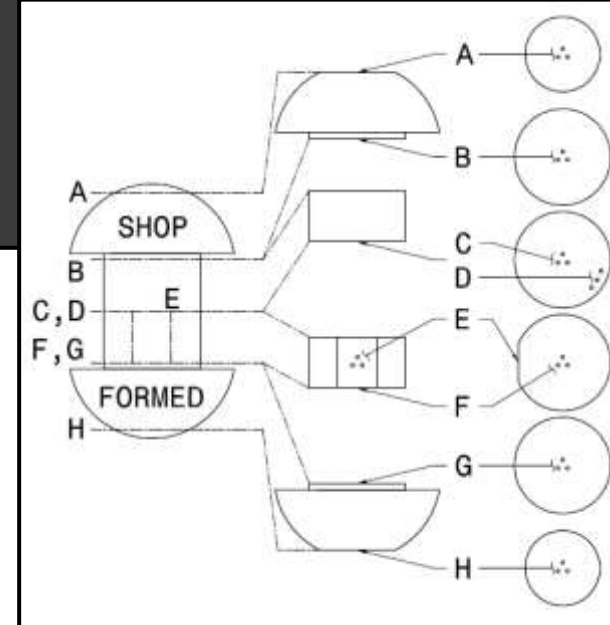
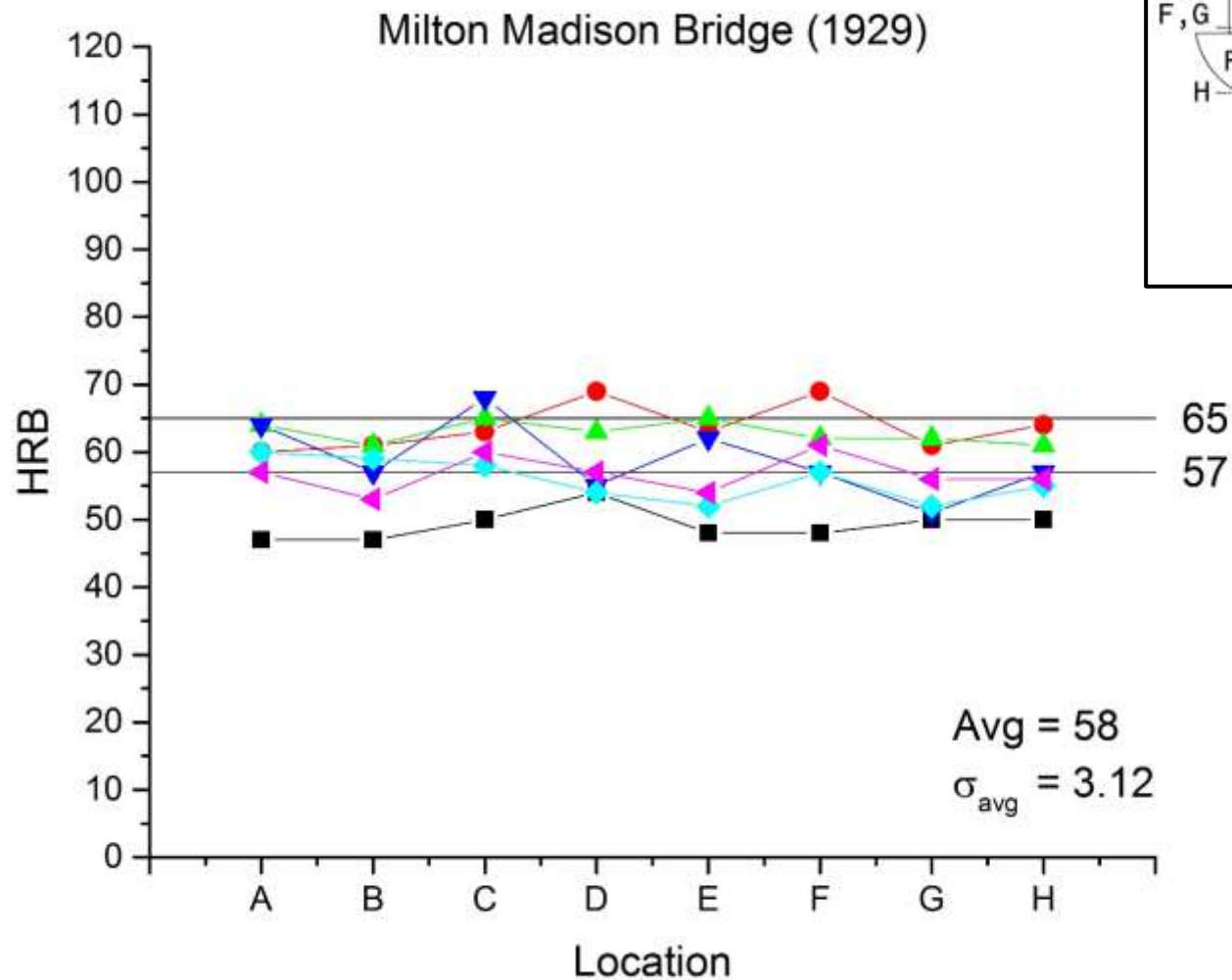
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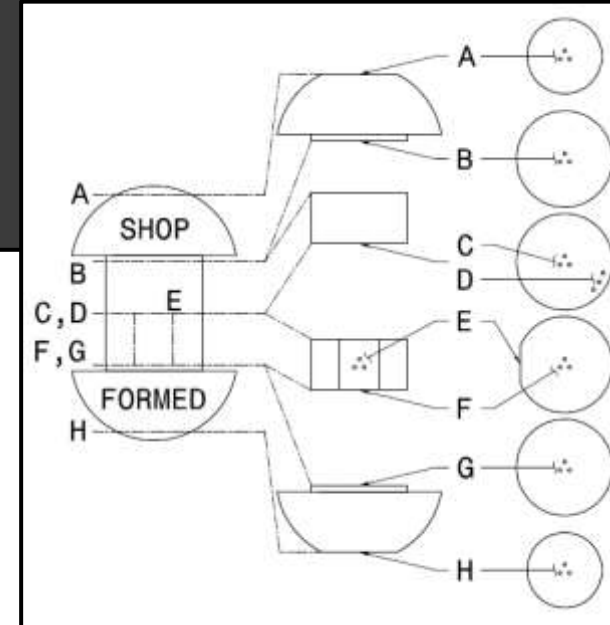
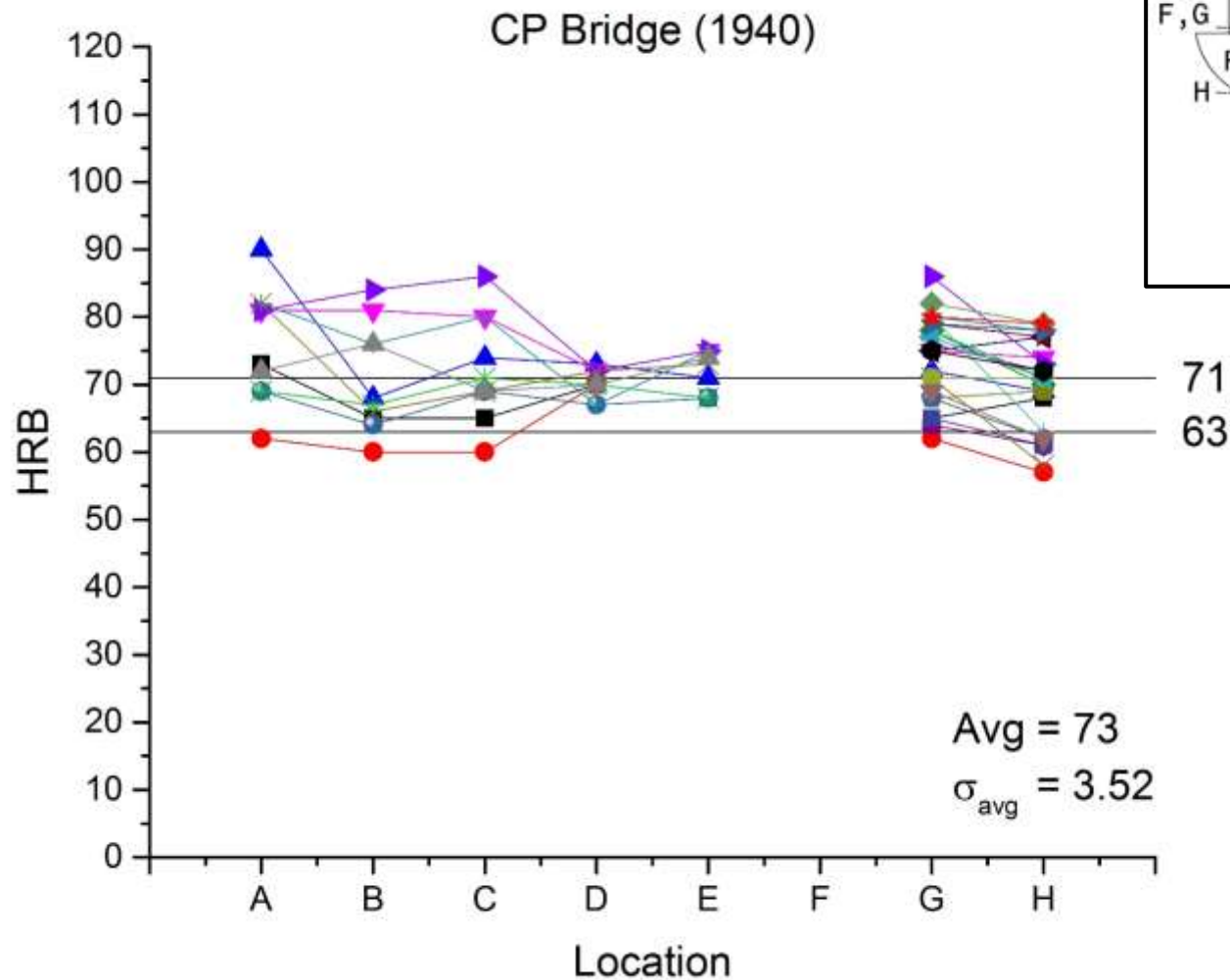
# Hardness Data



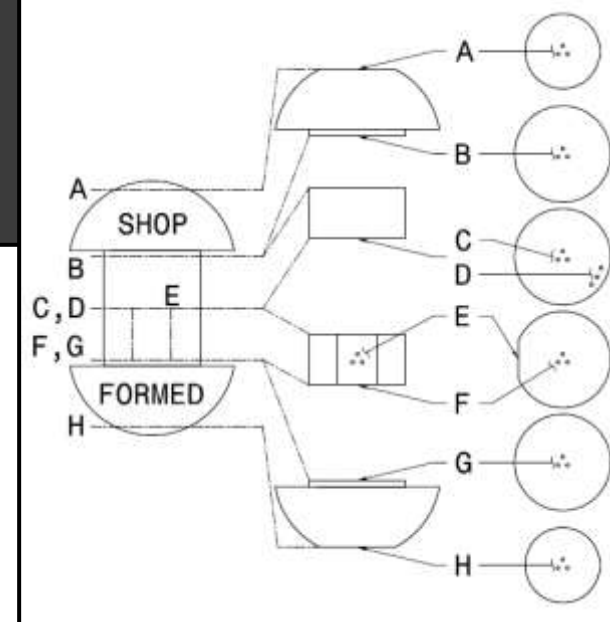
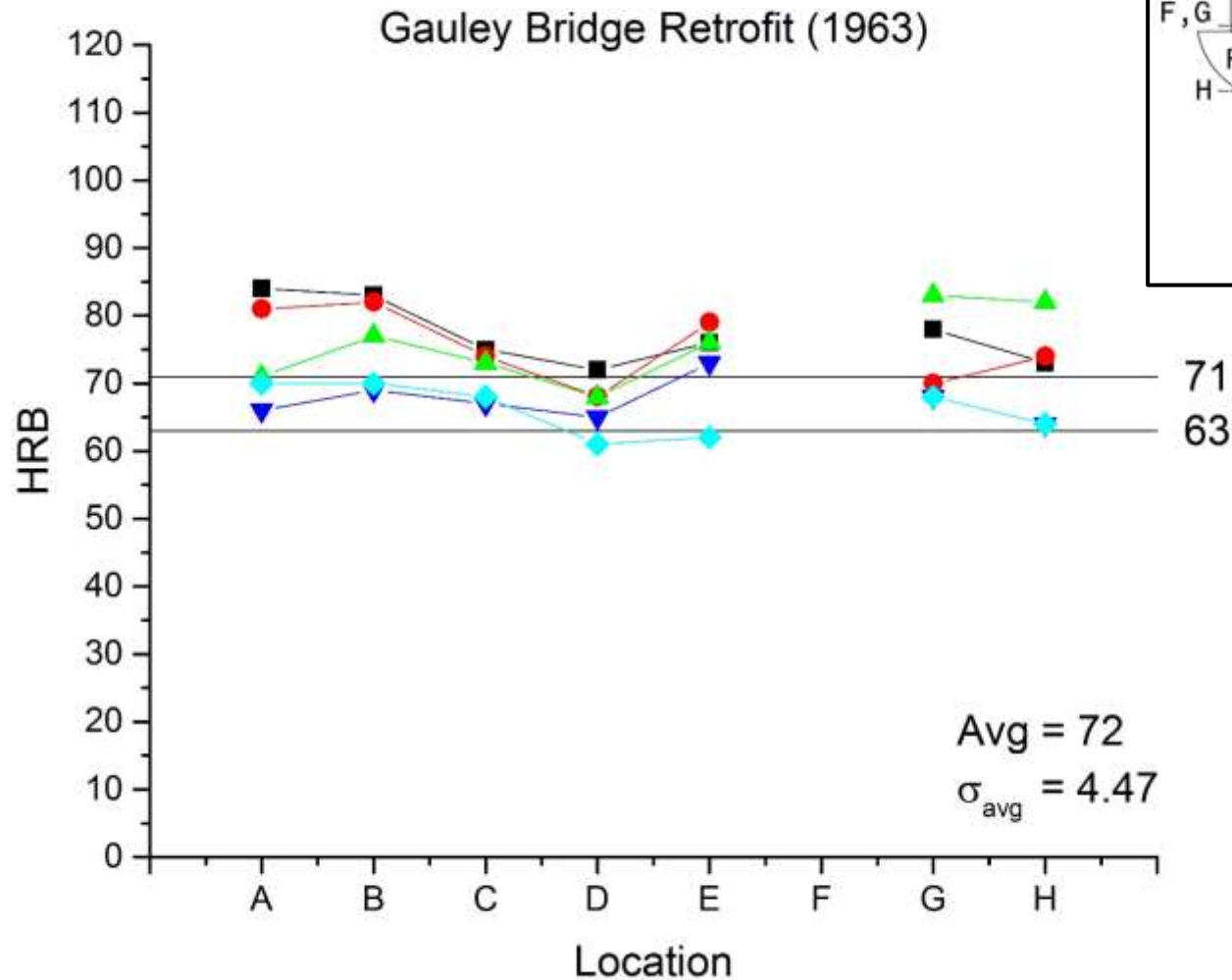
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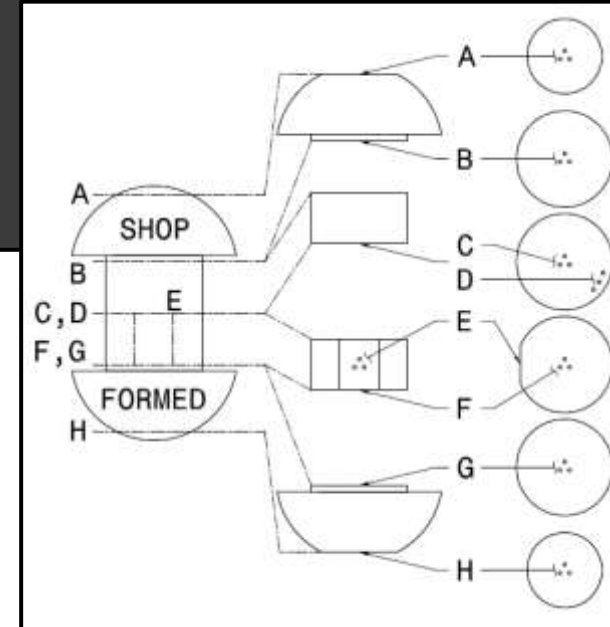
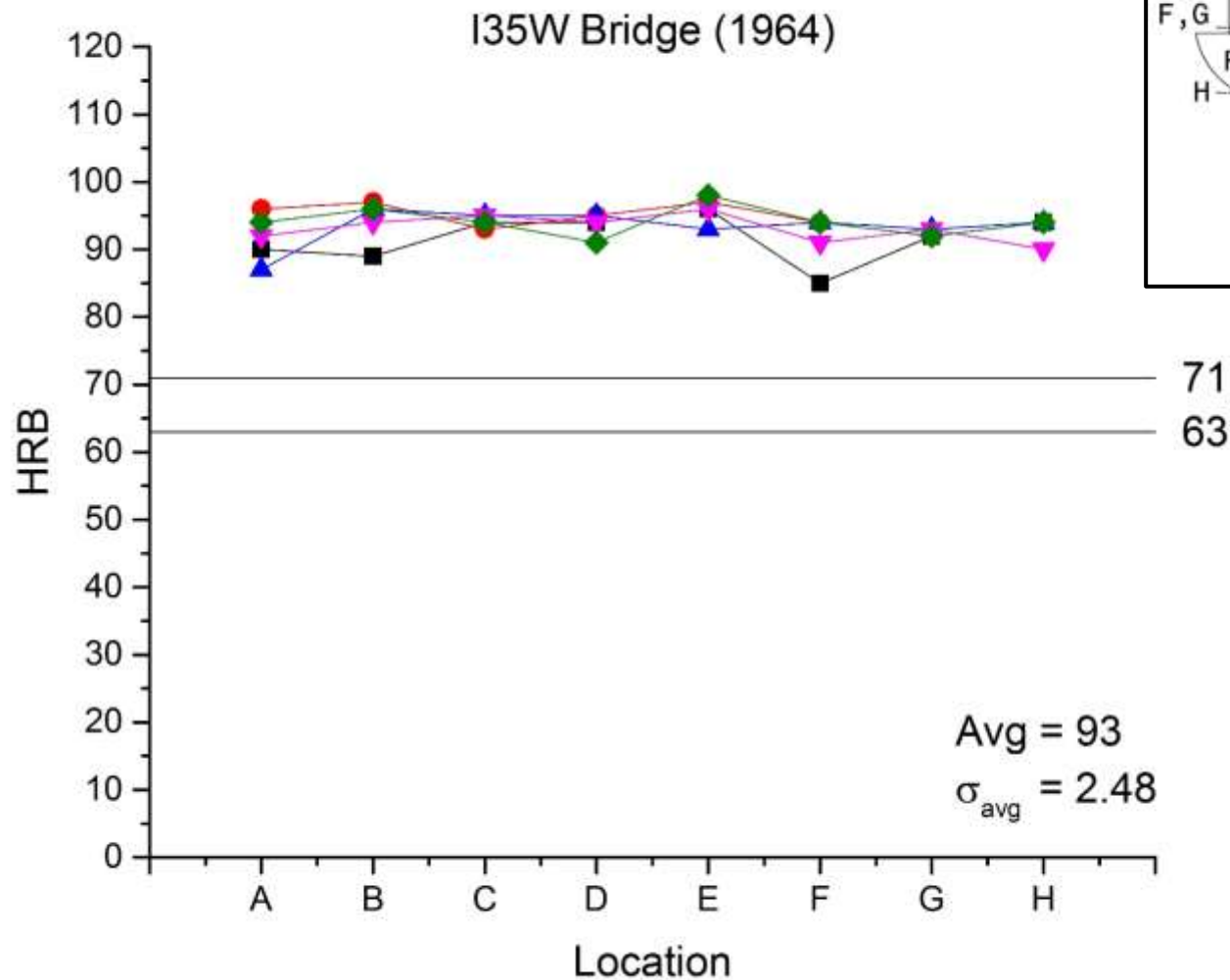
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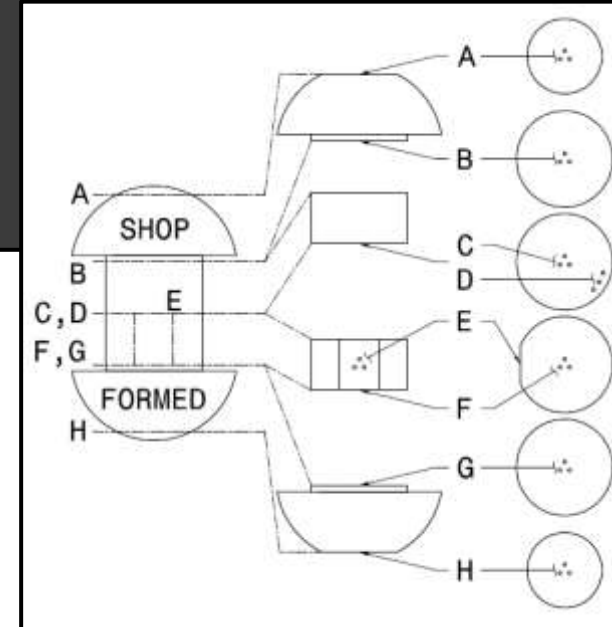
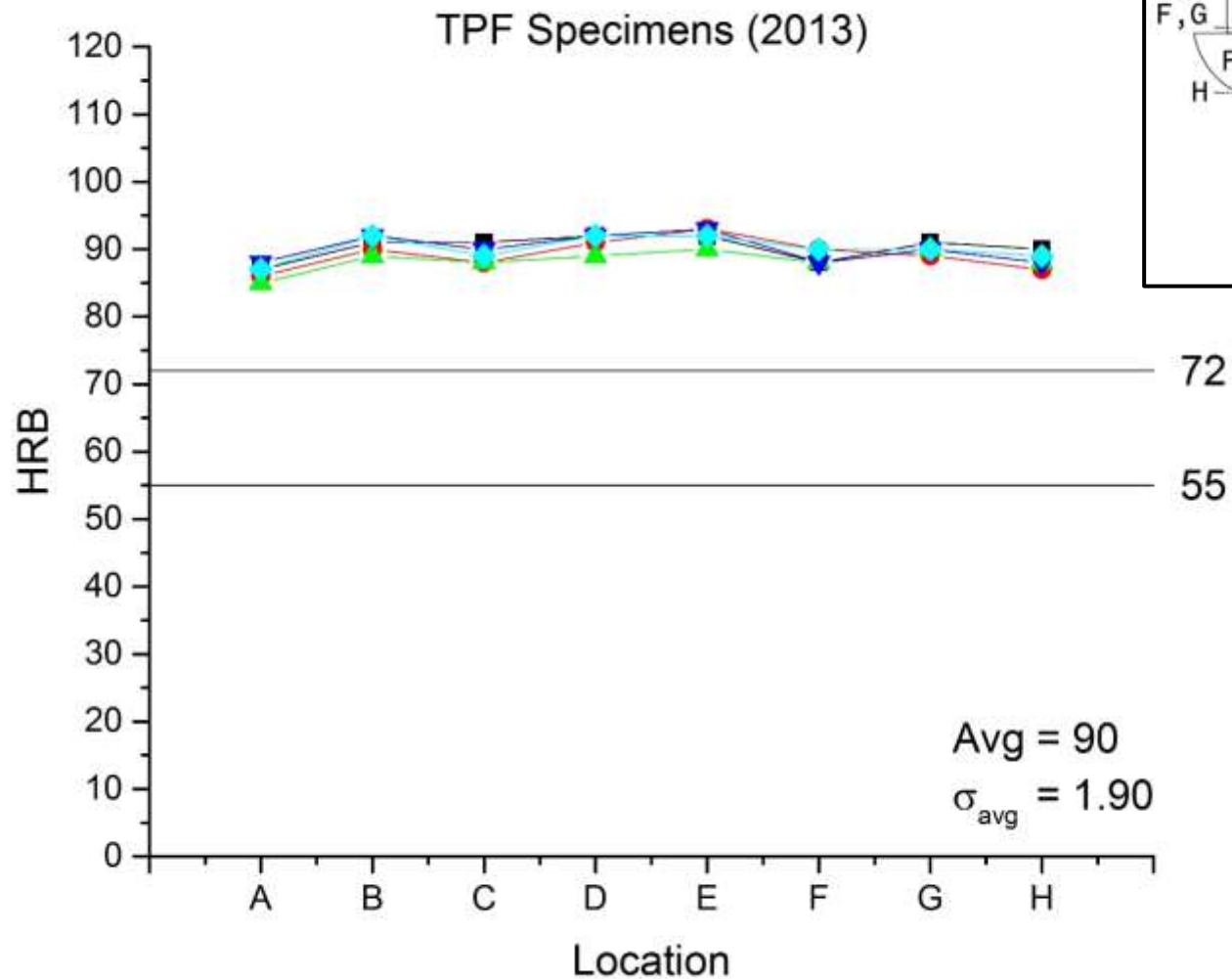
# Hardness Data



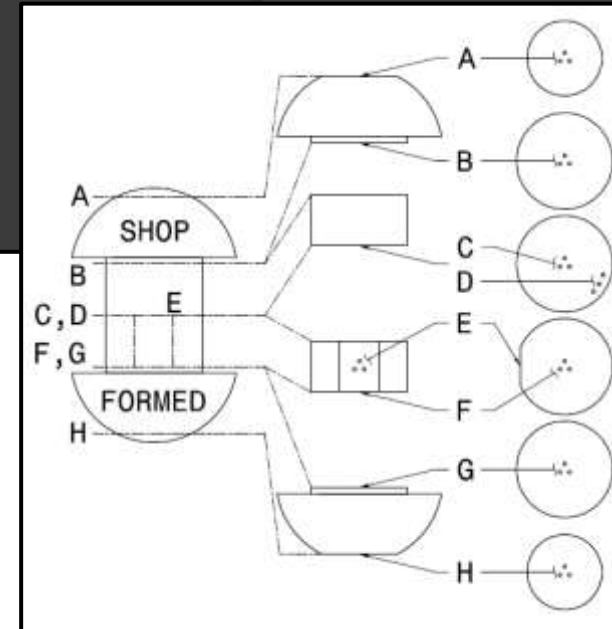
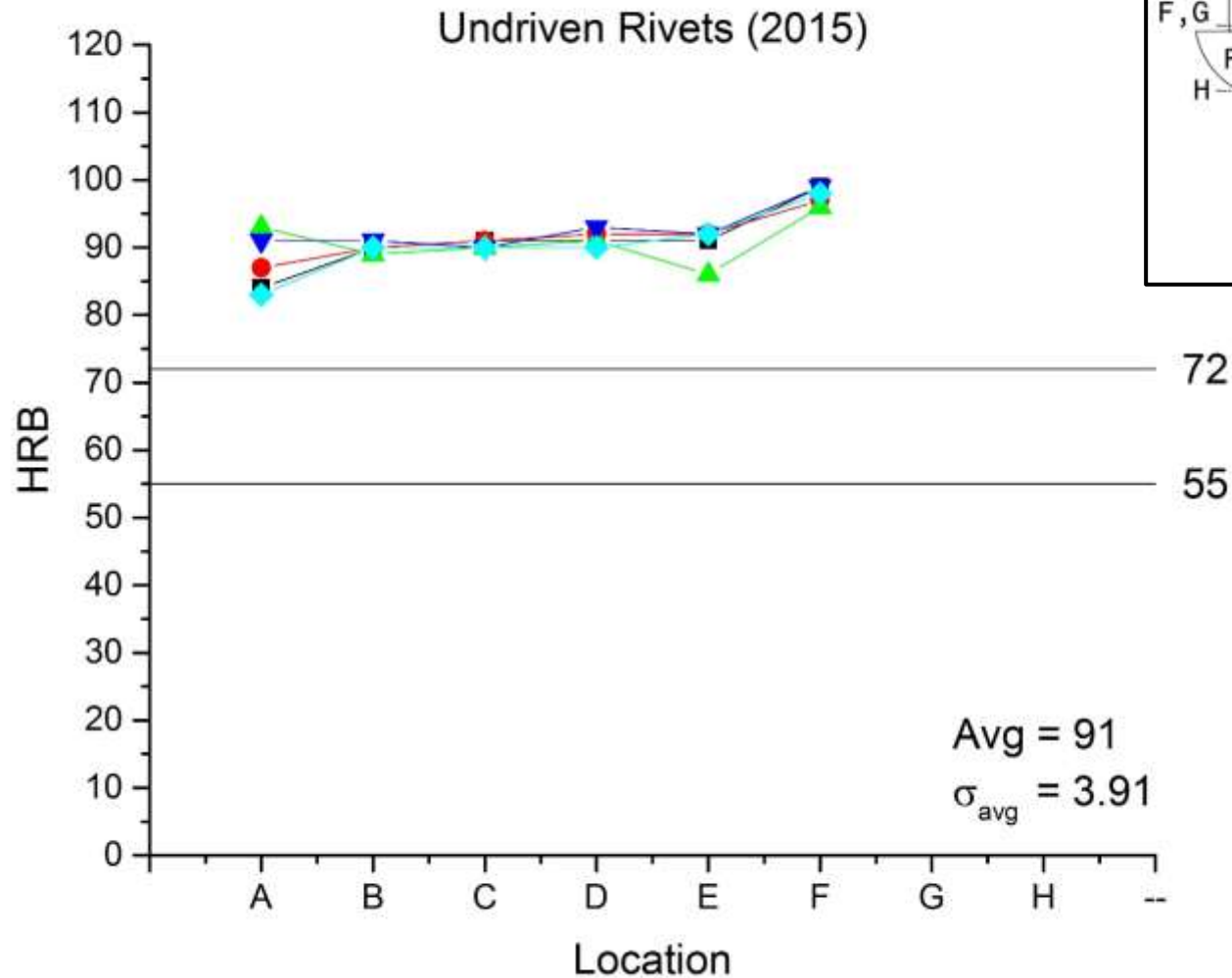
# Hardness Data



# Hardness Data



# Hardness Data



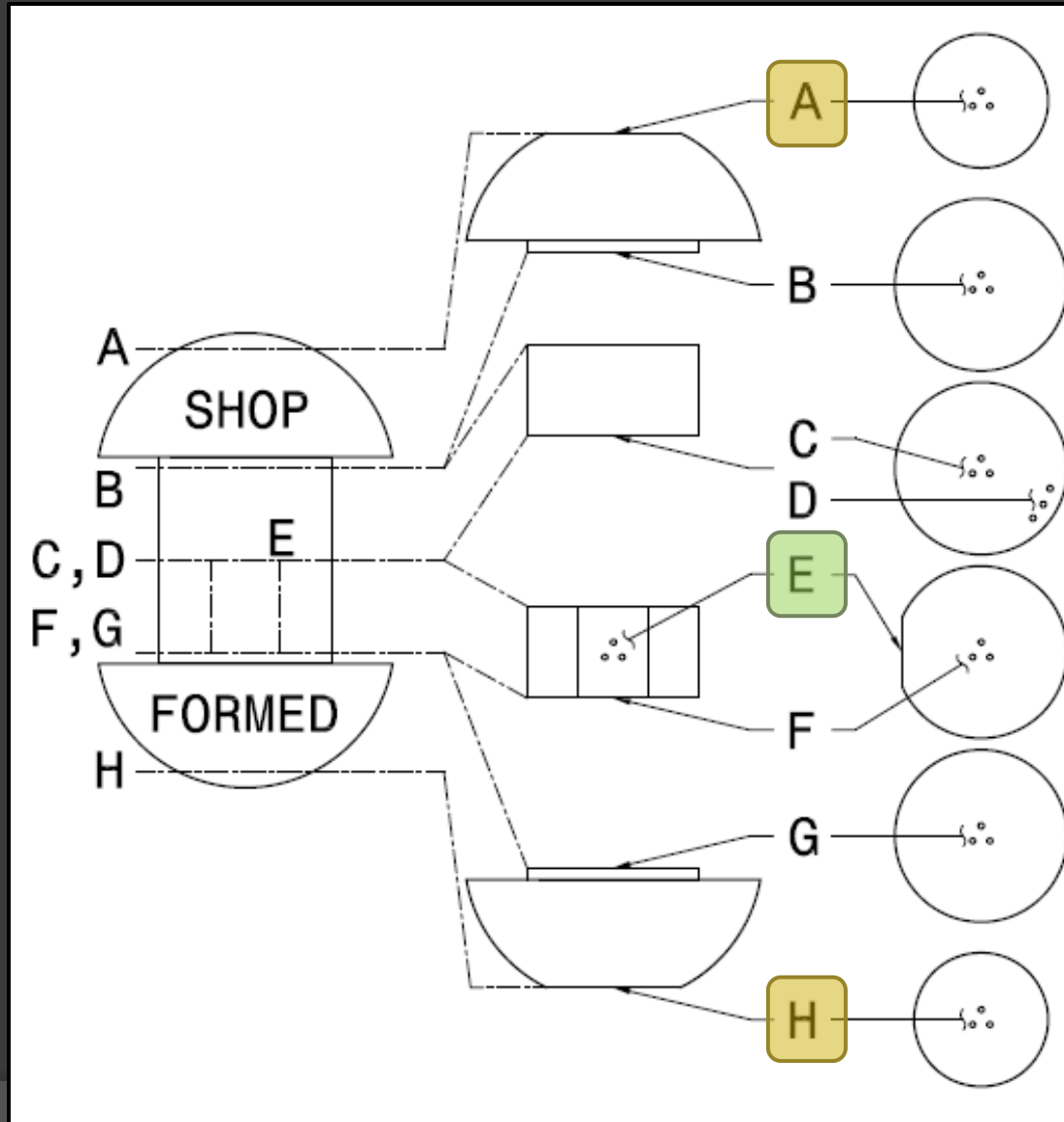
# Data Summary

| Source of Rivets                 | Avg HRB | Avg Standard Deviation |
|----------------------------------|---------|------------------------|
| BNSF Bridge (1890)               | 72      | 2.25                   |
| Gauley Bridge (1892)             | 73      | 3.05                   |
| Wilson Dam Bascule Bridge (1925) | 67      | 4.07                   |
| Milton Madison Bridge (1929)     | 58      | 3.12                   |
| CP Bridge (1940)                 | 73      | 3.52                   |
| Gauley Bridge Retrofit (1963)    | 72      | 4.47                   |
| I-35W Bridge (1964)              | 93      | 2.48                   |
| TPF Research (2013)              | 90      | 1.90                   |
| Undriven Rivets (2015)           | 91      | 3.91                   |

# Data Summary

| Source of Rivets                 | Avg<br>Max HRB<br>Head | Avg<br>Min HRB<br>Shank | Avg<br>Shank<br>/Head |
|----------------------------------|------------------------|-------------------------|-----------------------|
| BNSF Bridge (1890)               | 74                     | 68                      | 0.92                  |
| Gauley Bridge (1892)             | 74                     | 68                      | 0.92                  |
| Wilson Dam Bascule Bridge (1925) | 65                     | 63                      | 0.97                  |
| Milton Madison Bridge (1929)     | 60                     | 54                      | 0.90                  |
| CP Bridge (1940)                 | 73                     | 72                      | 0.99                  |
| Gauley Bridge Retrofit (1963)    | 77                     | 67                      | 0.87                  |
| I-35W Bridge (1964)              | 94                     | 90                      | 0.96                  |
| TPF Research (2013)              | 88                     | 88                      | 1.00                  |
| Undriven Rivets (2015)           | 88                     | 89                      | 1.01                  |

# Test Locations



# Data Summary

| Source of Rivets                 | Avg<br>HRB<br>Head | $\sigma$<br>HRB<br>Head | Avg<br>HRB<br>Shank<br>(E) | $\sigma$<br>HRB<br>Shank<br>(E) | Avg<br>Shank<br>/Head |
|----------------------------------|--------------------|-------------------------|----------------------------|---------------------------------|-----------------------|
| BNSF Bridge (1890)               | 72.6               | 3.1                     | 70.2                       | 2.6                             | 0.97                  |
| Gauley Bridge (1892)             | 72.6               | 5.8                     | 69.7                       | 7.3                             | 0.96                  |
| Wilson Dam Bascule Bridge (1925) | 64.2               | 2.0                     | 73.8                       | 3.7                             | 1.15                  |
| Milton Madison Bridge (1929)     | 57.9               | 5.4                     | 57.3                       | 6.9                             | 0.99                  |
| CP Bridge (1940)                 | 71.7               | 7.8                     | 71.5                       | 3.2                             | 1.00                  |
| Gauley Bridge Retrofit (1963)    | 72.9               | 7.4                     | 73.2                       | 6.6                             | 1.00                  |
| I-35W Bridge (1964)              | 92.5               | 2.7                     | 96.0                       | 1.9                             | 1.04                  |
| TPF Research (2013)              | 87.5               | 1.4                     | 92.0                       | 1.2                             | 1.05                  |
| Undriven Rivets (2015)           | 87.6               | 4.3                     | 90.6                       | 2.6                             | 1.03                  |

# Conclusions

- ◎ Generally meets the specifications
- ◎ Minimal variability through an individual rivet
- ◎ Head is representative of shank
- ◎ Rivet head hardness is a suitable representation of rivet strength

# Future Work

- ◎ Compare driving method
- ◎ Additional bridges from S-BRITE
- ◎ Evaluate handheld hardness tester

# Questions?

