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# Consideration and Testing in Support of a Potential Standardized Perforator Hole Size Test

IPS 16-46

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# AGENDA/INTRODUCTION

- Testing Background
- Need For Testing
- Feasibility Testing
- Test Method
- Test Results
- Test Discussion
- Conclusion
- Future Work
- Questions and Discussion

# TESTING BACKGROUND

## STANDARDIZED API TESTS

- Currently the only test that provides phased hole size data for a perforating charge/system is an API RP 19B Section 1 Test
- This limits the standard casing options for each perforating system
- Test design is used to determine system interference by measuring penetration and hole size
- Due to the penetration requirements of modern DP charges concrete targets must be large in diameter, between 96” and 156” in size
- Extremely cost prohibitive to shoot multiple tests

# NEED FOR TESTING

## CURRENT METHODS

- Currently hole size data can be collected by several methods, each having pros and cons

| Method | Pro | Con |
|---|---|---|
| QC/Coupon Test | Cost effective, quick, easy | Limited data, lacks boundary constraints |
| Barrel Test | Cost effective, easy | Limited data, still requires concrete target |
| Gun Test | Cost effective, quick, easy, large amount of data | Lacks formation confinement constraints |
| Section 1 Test | Accurate well scenario test | Expensive, time consuming |
| Computer Simulation | Cost effective, quick, easy | Potentially inaccurate due to limited input data |

- Is there a potential solution to provide a cost effective and accurate test for the industry?

# BENEFITS OF A HOLE SIZE SPECIFIC TEST

- A standardized test creates customer confidence in data
  - The manufacturer can provide a better answer to the question of charge performance
- It aids in development and focus on frac or specific/consistent entry hole size charges
- Collection of hole size data eventually allows for better modelling and simulation software
- Lastly, it allows for comparison of charge performance in similar scenarios

# RECOMMENDED TEST METHOD

- This topic is currently in initial talks within the API RP 19B subcommittee members consisting of Operators and Manufacturers
- Several iterations have been addressed and examined
- Currently, the test method allows:
  - Deep Penetrating and Good Hole Design style of charges to be used
  - Big Hole charges have been left out
    - BH tests are orders of magnitude less than DP due to target size
    - BH charges are far more dependent on the concrete confinement around the casing for performance
  - Conduct gun test in fluid or air
  - Suspend multiple casing strings on the gun carrier, minimum of 12 shots or 2’ consecutive perforating
  - Centralized or Decentralized
  - One string must be the same as the valid Section 1 test for a comparison of data for accuracy
  - Testing Company can choose alternate casing sizes, weights, grades, and orientations as they see fit for their needs, and potentially test through multiple casing strings

# FEASIBILITY TESTING CONDUCTED

## TEST SETUP

- 21’ perforating gun
- 6spf
- 60deg phasing
- 2’ of captured perforations
- 4 different casing string sizes
- No perforations captured within 3” of casing boundary

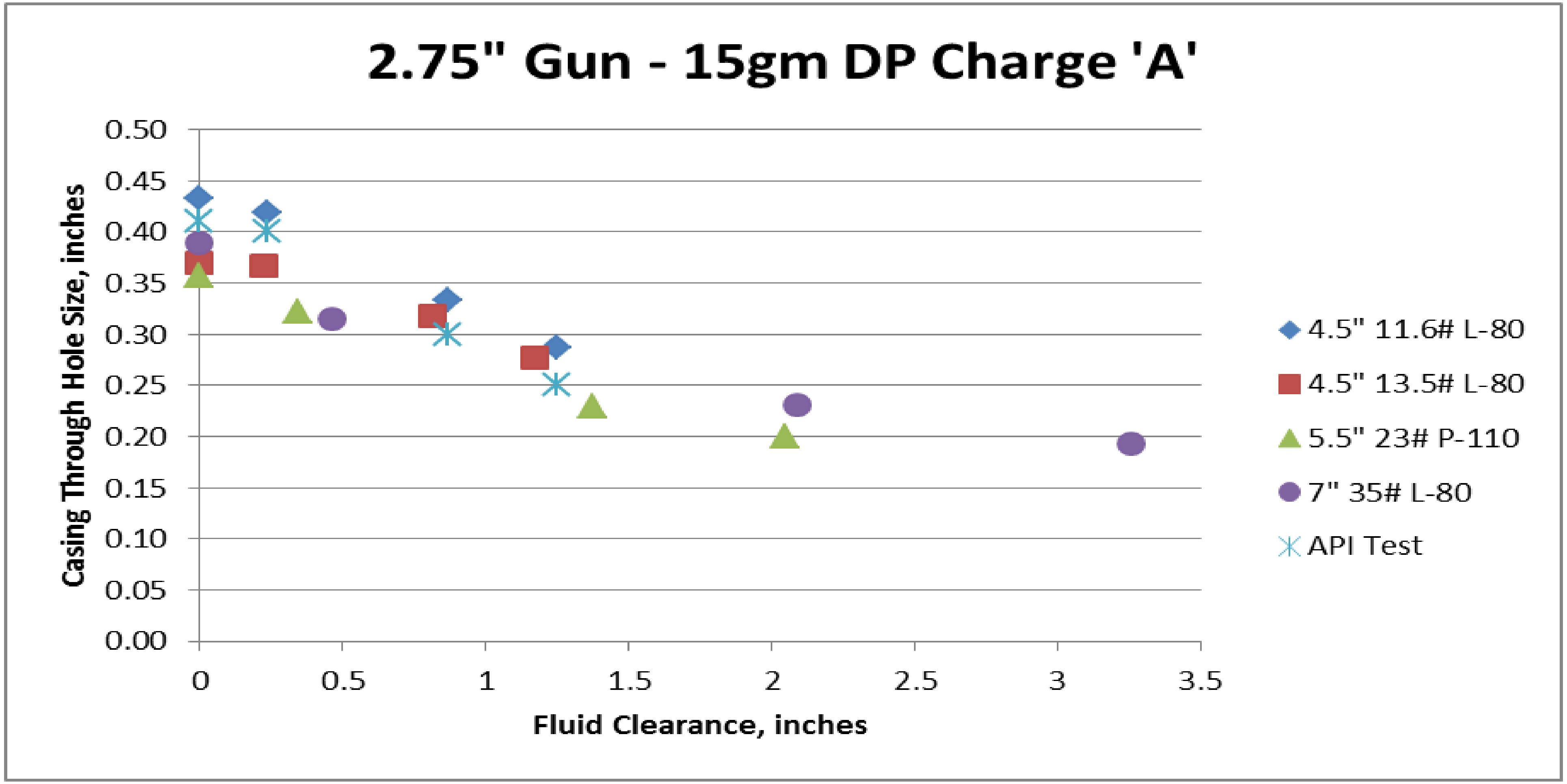
# TEST SETUP

- Examine 4 different style DP charge designs that have Section 1 data to compare against
- Examine 1 charge that can be shot in multiple gun sizes to determine system effects
- Test in one casing that was the same as Section 1
- Test in 3 other casings that vary in weight, wall thickness, grade, and diameter
- At least one casing size that have extreme far water clearances

| | | | | | |
|---|---|---|---|---|---|
| 15 Gm DP Charge 'A' | 2.75" | 4.5" 11.6# L-80 | 4.5" 13.5# L_80 | 5.5" 23# P-110 | 7" 35# L-80 |
| 21 gm DP Charge 'B' | 3.125 | 4.5" 11.6# L-80 | 5.5" 23# P-110 | 7" 35# L-80 | 9.625" 53.5# P-110 |
| | 3.375 | | | | |
| 21 gm DP Charge 'C' | 3.125 | | | | |
| 25 gm DP Charge 'D' | 3.375 | | | | |

# 2.75” SYSTEM DATA

## 15 GRAM CHARGE ‘A’



# 2.75” SYSTEM DATA

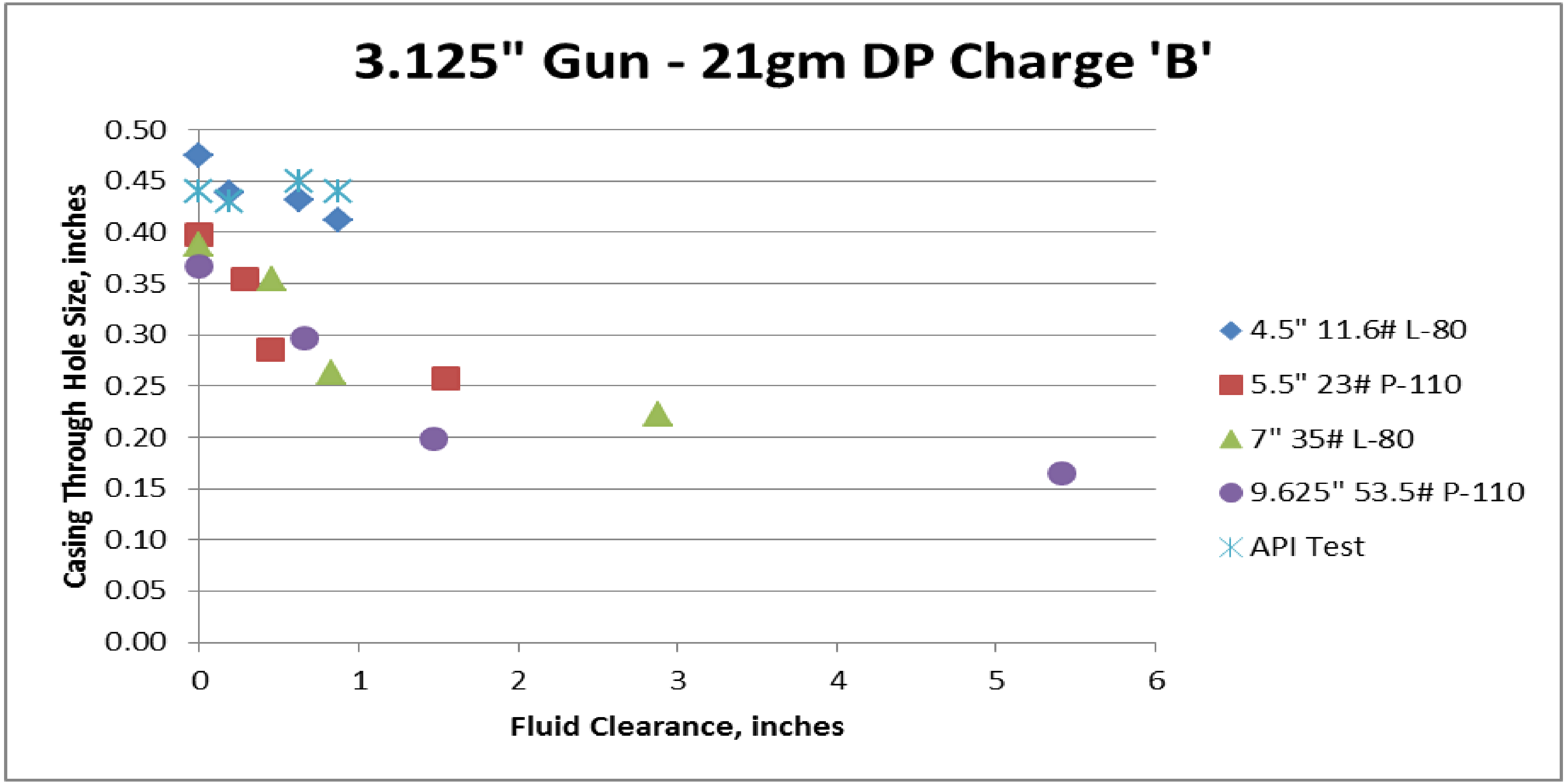
## 15 GRAM CHARGE ‘A’

- API Confined vs Unconfined showed 8.5% larger hole size with no confinement
- Average simulation error was 14.4%
- Minimum simulation was -43% below actual results
- Maximum simulation was 58% over actual results

| Performance Results | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | API TEST DATA 4.5" 11.6# | | | | | 4.5" 11.6# | | | | | 4.5" 13# | | | | | 5.5" 20# | | | | | 7" 35# | | | | |
| | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg |
| Test Data | 0.41 | 0.40 | 0.30 | 0.25 | 0.34 | 0.43 | 0.42 | 0.33 | 0.29 | 0.37 | 0.37 | 0.37 | 0.32 | 0.28 | 0.34 | 0.36 | 0.32 | 0.23 | 0.20 | 0.28 | 0.39 | 0.32 | 0.23 | 0.19 | 0.28 |
| Simulation 1 | 0.40 | 0.42 | 0.41 | 0.38 | 0.41 | 0.40 | 0.42 | 0.41 | 0.38 | 0.41 | 0.39 | 0.40 | 0.4 | 0.37 | 0.39 | 0.39 | 0.41 | 0.36 | 0.3 | 0.37 | 0.39 | 0.41 | 0.36 | 0.3 | 0.37 |
| Simulation 2 | 0.40 | 0.40 | 0.30 | 0.25 | 0.34 | 0.40 | 0.40 | 0.30 | 0.25 | 0.34 | 0.38 | 0.36 | 0.24 | 0.16 | 0.29 | 0.38 | 0.36 | 0.24 | 0.16 | 0.29 | 0.40 | 0.36 | 0.15 | 0.13 | 0.26 |
| Simulation 1 Error | -2% | 5% | 37% | 52% | 18% | -7% | 0% | 24% | 31% | 10% | 5% | 8% | 25% | 32% | 16% | 8% | 28% | 57% | 50% | 33% | 0% | 28% | 57% | 58% | 33% |
| Simulation 2 Error | -2% | 0% | 0% | 0% | 0% | -7% | -5% | -9% | -14% | -8% | 3% | -3% | -25% | -43% | -14% | 6% | 13% | 4% | -20% | 4% | 3% | 13% | -35% | -32% | -8% |

# 3.125" SYSTEM DATA

## 21 GRAM CHARGE 'B'



# 3.125” SYSTEM DATA

## 21 GRAM CHARGE ‘B’

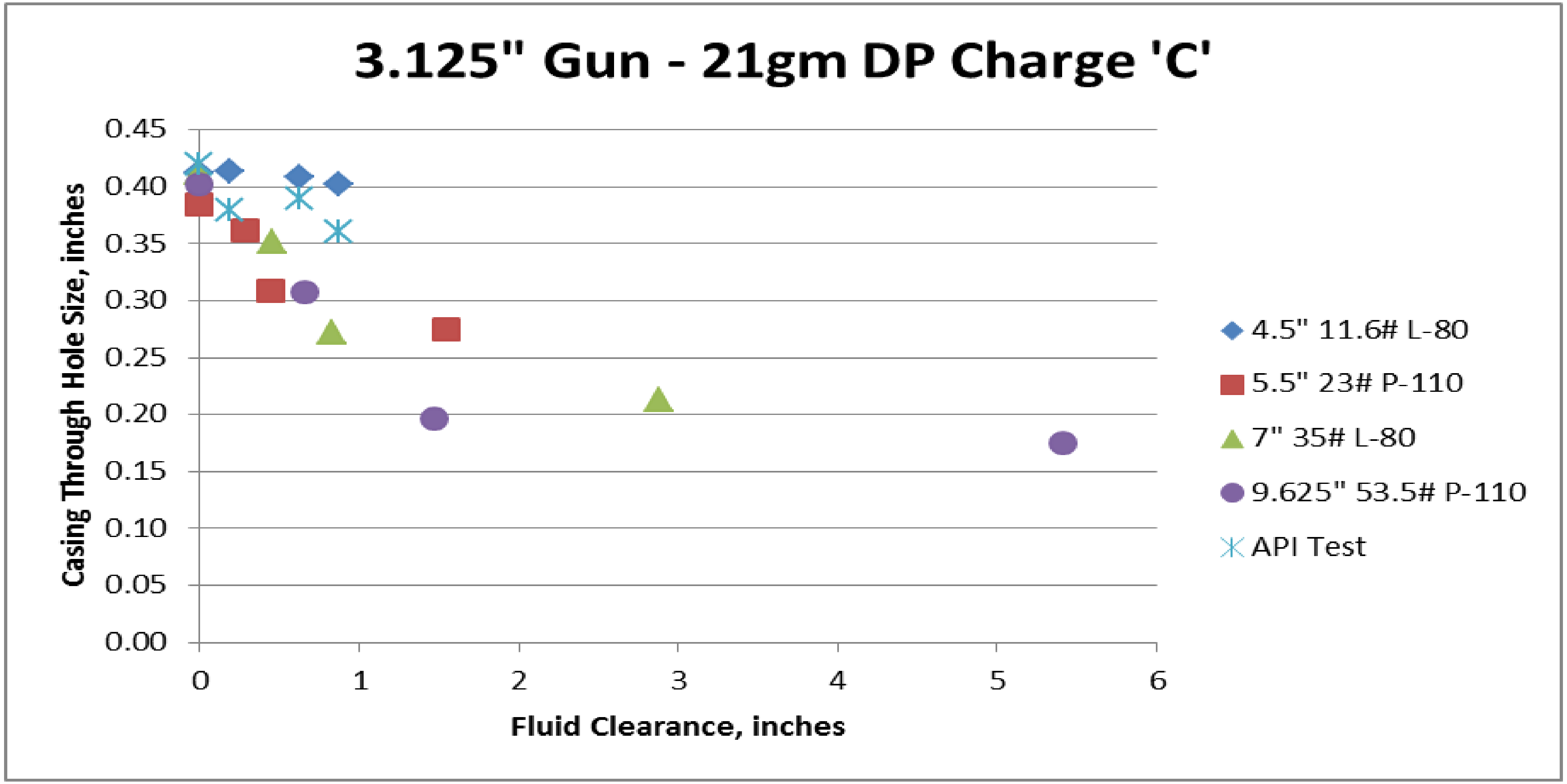
- API Confined vs Unconfined showed no change in performance
- Average simulation error was 8.3%
- Minimum simulation was -41% below actual results
- Maximum simulation was 40% over actual results

**Performance Results**

| | API TEST DATA 4.5" 11.6# | | | | | 4.5" 11.6# | | | | | 5.5" 23# | | | | | 7" 35# | | | | | 9.625" 53.5# | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** |
| Test Data | 0.44 | 0.43 | 0.45 | 0.44 | 0.44 | 0.48 | 0.44 | 0.43 | 0.41 | 0.44 | 0.40 | 0.35 | 0.29 | 0.26 | 0.32 | 0.39 | 0.36 | 0.26 | 0.22 | 0.31 | 0.37 | 0.30 | 0.20 | 0.17 | 0.25 |
| Simulation 1 | 0.46 | 0.43 | 0.42 | 0.39 | 0.43 | 0.46 | 0.43 | 0.42 | 0.39 | 0.43 | 0.44 | 0.41 | 0.35 | 0.29 | 0.38 | 0.46 | 0.42 | 0.27 | 0.18 | 0.34 | 0.44 | 0.40 | 0.15 | 0.10 | 0.27 |
| Simulation 2 | 0.41 | 0.45 | 0.44 | 0.38 | 0.43 | 0.41 | 0.45 | 0.44 | 0.38 | 0.43 | 0.36 | 0.42 | 0.20 | 0.20 | 0.30 | 0.38 | 0.45 | 0.28 | 0.21 | 0.34 | 0.36 | 0.42 | 0.2 | 0.2 | 0.30 |
| Simulation 1 Error | 5% | 0% | -7% | -11% | -3% | -4% | -2% | -2% | -5% | -3% | 10% | 17% | 21% | 12% | 17% | 18% | 17% | 4% | -18% | 9% | 19% | 33% | -25% | -41% | 9% |
| Simulation 2 Error | -7% | 5% | -2% | -14% | -3% | -15% | 2% | 2% | -7% | -3% | -10% | 20% | -31% | -23% | -6% | -3% | 25% | 8% | -5% | 10% | -3% | 40% | 0% | 18% | 20% |

# 3.125” SYSTEM DATA

## 21 GRAM CHARGE ‘C’



# 3.125" SYSTEM DATA

## 21 GRAM CHARGE 'C'

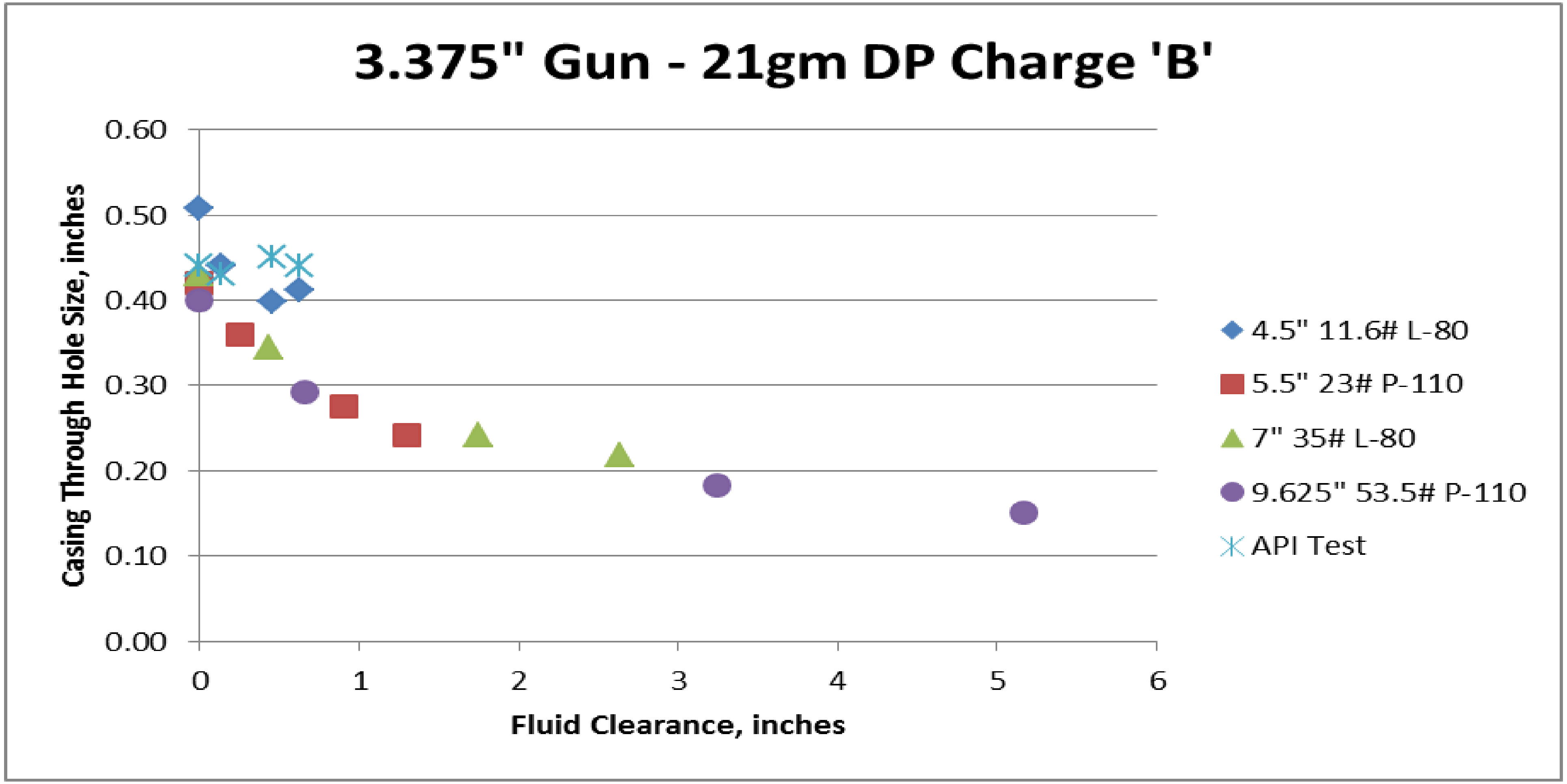
- API Confined vs Unconfined showed 5.0% larger hole size with no confinement
- Average Simulation error was 4.8%
- Minimum simulation was -50% below actual results
- Maximum simulation was 26% over actual results

**Performance Results**

| Method | API TEST DATA 4.5" 11.6# | | | | | 4.5" 11.6# | | | | | 5.5" 23# | | | | | 7" 35# | | | | | 9.625" 53.5# | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg | 0 | 60 | 120 | 180 | Avg |
| Test Data | 0.42 | 0.38 | 0.39 | 0.36 | 0.39 | 0.41 | 0.41 | 0.41 | 0.40 | 0.41 | 0.39 | 0.36 | 0.31 | 0.28 | 0.33 | 0.41 | 0.35 | 0.27 | 0.21 | 0.32 | 0.40 | 0.31 | 0.20 | 0.18 | 0.26 |
| Simulation 1 | 0.38 | 0.43 | 0.40 | 0.33 | 0.40 | 0.38 | 0.43 | 0.40 | 0.33 | 0.40 | 0.37 | 0.43 | 0.27 | 0.20 | 0.33 | 0.38 | 0.43 | 0.17 | 0.13 | 0.29 | 0.37 | 0.38 | 0.12 | 0.09 | 0.24 |
| Simulation 2 | 0.39 | 0.41 | 0.39 | 0.35 | 0.39 | 0.39 | 0.41 | 0.39 | 0.35 | 0.39 | 0.33 | 0.37 | 0.35 | 0.31 | 0.35 | 0.35 | 0.40 | 0.30 | 0.22 | 0.33 | 0.33 | 0.39 | 0.20 | 0.20 | 0.29 |
| Simulation 1 Error | -10% | 13% | 3% | -8% | 2% | -7% | 5% | -2% | -18% | -4% | -5% | 19% | -13% | -29% | -1% | -7% | 23% | -37% | -38% | -11% | -8% | 23% | -40% | -50% | -6% |
| Simulation 2 Error | -7% | 8% | 0% | -3% | 1% | -5% | 0% | -5% | -13% | -5% | -15% | 3% | 13% | 11% | 5% | -15% | 14% | 11% | 5% | 3% | -18% | 26% | 0% | 11% | 10% |

# 3.375” SYSTEM DATA

## 21 GRAM CHARGE ‘B’



# 3.375” SYSTEM DATA

## 21 GRAM CHARGE ‘B’

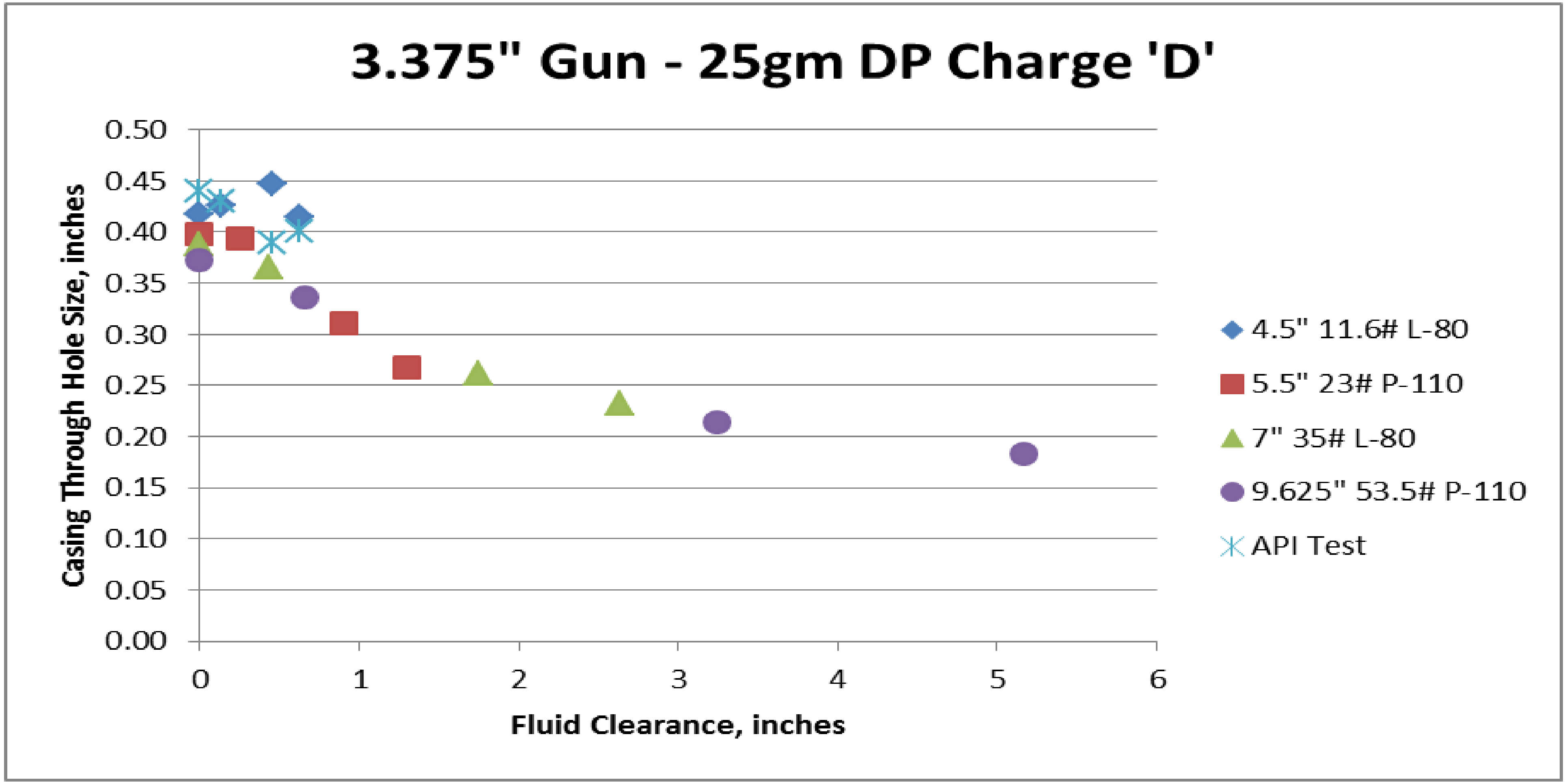
- API Confined vs Unconfined showed 2.3% smaller hole size with no confinement
- Average Simulation error was 26%
- Minimum simulation was -14% below actual results
- Maximum simulation was 139% over actual results

**Performance Results**

| Method | API TEST DATA 4.5" 11.6# | | | | | 4.5" 11.6# | | | | | 5.5" 23# | | | | | 7" 35# | | | | | 9.625" 53.5# | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** |
| Test Data | 0.44 | 0.43 | 0.45 | 0.44 | **0.44** | 0.51 | 0.44 | 0.40 | 0.41 | **0.43** | 0.42 | 0.36 | 0.28 | 0.24 | **0.32** | 0.43 | 0.34 | 0.24 | 0.22 | **0.30** | 0.40 | 0.29 | 0.18 | 0.15 | **0.25** |
| Simulation 1 | 0.44 | 0.44 | 0.47 | 0.47 | **0.46** | 0.44 | 0.44 | 0.47 | 0.47 | **0.46** | 0.43 | 0.43 | 0.43 | 0.41 | **0.43** | 0.44 | 0.46 | 0.4 | 0.34 | **0.42** | 0.43 | 0.45 | 0.3 | 0.2 | **0.36** |
| Simulation 2 | 0.44 | 0.44 | 0.44 | 0.44 | **0.44** | 0.44 | 0.44 | 0.44 | 0.44 | **0.44** | 0.42 | 0.42 | 0.41 | 0.41 | **0.42** | 0.44 | 0.44 | 0.43 | 0.44 | **0.44** | 0.42 | 0.42 | 0.43 | 0.27 | **0.40** |
| Simulation 1 Error | 0% | 2% | 4% | 7% | **3%** | -14% | 0% | 18% | 15% | **6%** | 2% | 19% | 54% | 71% | **33%** | 2% | 35% | 67% | 55% | **39%** | 7% | 55% | 67% | 33% | **42%** |
| Simulation 2 Error | 0% | 2% | -2% | 0% | **0%** | -14% | 0% | 10% | 7% | **2%** | 0% | 17% | 46% | 71% | **30%** | 2% | 29% | 79% | 100% | **46%** | 5% | 45% | 139% | 80% | **59%** |

# 3.375" SYSTEM DATA

## 25 GRAM CHARGE 'D'



# 3.375" SYSTEM DATA

## 25 GRAM CHARGE 'D'

- API Confined vs Unconfined showed 4.8% larger hole size with no confinement
- Average Simulation error was 9.3%
- Minimum simulation was -28% below actual results
- Maximum simulation was 44% over actual results

| Performance Results | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **API TEST DATA 4.5" 11.6#** | | | | | **4.5" 11.6#** | | | | | **5.5" 23#** | | | | | **7" 35#** | | | | | **9.625" 53.5#** | | | | |
| **Method** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** | **0** | **60** | **120** | **180** | **Avg** |
| Test Data | 0.44 | 0.43 | 0.39 | 0.40 | **0.41** | 0.42 | 0.43 | 0.45 | 0.42 | **0.43** | 0.40 | 0.39 | 0.31 | 0.27 | **0.35** | 0.39 | 0.37 | 0.26 | 0.23 | **0.31** | 0.37 | 0.34 | 0.21 | 0.18 | **0.28** |
| Simulation 1 | 0.52 | 0.49 | 0.42 | 0.41 | **0.46** | 0.52 | 0.49 | 0.42 | 0.41 | **0.46** | 0.50 | 0.44 | 0.4 | 0.37 | **0.43** | 0.52 | 0.43 | 0.33 | 0.23 | **0.38** | 0.50 | 0.4 | 0.19 | 0.13 | **0.30** |
| Simulation 2 | 0.44 | 0.43 | 0.39 | 0.39 | **0.41** | 0.44 | 0.43 | 0.39 | 0.39 | **0.41** | 0.42 | 0.4 | 0.35 | 0.32 | **0.37** | 0.44 | 0.39 | 0.3 | 0.22 | **0.34** | 0.42 | 0.37 | 0.19 | 0.19 | **0.29** |
| Simulation 1 Error | 18% | 14% | 8% | 2% | **11%** | 24% | 14% | -7% | -2% | **7%** | 25% | 13% | 29% | 37% | **21%** | 33% | 16% | 27% | 0% | **22%** | 35% | 18% | -10% | -28% | **8%** |
| Simulation 2 Error | 0% | 0% | 0% | -3% | **0%** | 5% | 0% | -13% | -7% | **-4%** | 5% | 3% | 13% | 19% | **7%** | 13% | 5% | 15% | -4% | **10%** | 14% | 9% | -10% | 6% | **3%** |

# DATA ANALYSIS

## Average Hole Size per Casing String

- Average Simulation error was 15%
- Minimum simulation was -20% below actual results
- Maximum simulation was 59% over actual results

**Test Results Summary**

| Gun Size | 2.75" | | | | 3.125" | | | | | | | | 3.375" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Charge | Charge 'A' | | | | Charge 'B' | | | | Charge 'C' | | | | Charge 'B' | | | | Charge 'D' | | | |
| Casing Diameter and Weight | 4.5" 11.6# | 4.5" 13.5# | 5.5" 23# | 7" 35# | 4.5" 11.6# | 5.5" 23# | 7" 35# | 9.625" 53.5# | 4.5" 11.6# | 5.5" 23# | 7" 35# | 9.625" 53.5# | 4.5" 11.6# | 5.5" 23# | 7" 35# | 9.625" 53.5# | 4.5" 11.6# | 5.5" 23# | 7" 35# | 9.625" 53.5# |
| Avg. Test Hole Size | 0.37 | 0.34 | 0.28 | 0.28 | 0.44 | 0.32 | 0.31 | 0.25 | 0.41 | 0.33 | 0.32 | 0.26 | 0.43 | 0.32 | 0.30 | 0.25 | 0.43 | 0.35 | 0.31 | 0.28 |
| Average Simulation 1 Hole Size | 0.41 | 0.39 | 0.37 | 0.37 | 0.43 | 0.38 | 0.34 | 0.27 | 0.40 | 0.33 | 0.29 | 0.24 | 0.46 | 0.43 | 0.42 | 0.36 | 0.46 | 0.43 | 0.38 | 0.30 |
| Average Error | 10% | 16% | 33% | 33% | -3% | 17% | 9% | 9% | -4% | -1% | -11% | -6% | 6% | 33% | 39% | 42% | 7% | 21% | 22% | 8% |
| Average Simulation 2 Hole Size | 0.34 | 0.29 | 0.29 | 0.26 | 0.43 | 0.30 | 0.34 | 0.30 | 0.39 | 0.35 | 0.33 | 0.29 | 0.44 | 0.42 | 0.44 | 0.40 | 0.41 | 0.37 | 0.34 | 0.29 |
| Average Error | -8% | -14% | -20% | -8% | -3% | -3% | 10% | 20% | -5% | 5% | 3% | 10% | 2% | 30% | 46% | 59% | -4% | 7% | -4% | 3% |

# DATA SUMMARY

- Both simulation methods used showed substantial variation and inconsistencies in the accuracy of their predictions
- There did not appear to be a common over or under prediction in performance
- The simulations showed large errors at a wide range of fluid clearances across the scenarios tested
- Test method showed a maximum of 8.5% variation from published Section 1 performance
- Standard Deviation did not increase substantially due to the reduced confinement effects

| Gun Size | Charge | API Section 1 Confined | | Unconfined Fluid Test | | Hole Size % Difference |
|---|---|---|---|---|---|---|
| | | Average Hole Size, in. | Standard Deviation, in. | Average Hole Size, in. | Standard Deviation, in. | |
| 2.75" | Charge 'A' | 0.34 | 0.06 | 0.37 | 0.08 | 8.5% |
| 3.125" | Charge 'B' | 0.44 | 0.02 | 0.44 | 0.03 | 0.0% |
| | Charge 'C' | 0.39 | 0.04 | 0.41 | 0.02 | 5.0% |
| 3.375" | Charge 'B' | 0.44 | 0.02 | 0.43 | 0.04 | 2.3% |
| | Charge 'D' | 0.41 | 0.04 | 0.43 | 0.02 | 4.8% |

# TEST BENEFITS

- Extremely quick and easy to conduct testing
- Does not require aging or curing of targets
- Can test in a wide range of casing sizes with a single gun test
- Can test effects of grade and yield in similar casing sizes while controlling test variables
- So far, has proven to have results that fall in line with Section 1 results and allowable tolerances
- Can be easily witnessed for a registered test
- Offers comparative data to compare against Section 1 data as a baseline metric
- Most importantly, provides a true and tested value to performance that is more accurate than some simulations can achieve

# CONCLUSIONS

- Appears to have minimal performance variation in the 4 Deep Penetrating charge designs tested in this research
- Big Hole designs have not been proven out, however this has not been discussed as being necessary for them
- Could be a viable test options for unique multistring perforating designs
- Has been proven in limited testing to be within tolerances to API Section 1 test results
- To date, there has been a growing interest in collecting accurate Hole Size performance data in alternate casings to justify pursuing this initiative
- Section 1 casing recommendations are often not used for the gun sizes found in the standard
- This recommended test method offers a viable, cost effective, timely, and beneficial solution to obtaining shaped charge hole size performance

# FUTURE WORK

- This venture will require industry acceptance and to be proven out on a larger scale before it could be recommended as a testing standard
- This method would potentially require testing across several manufacturers to determine the accuracy across a range of perforating designs

# QUESTIONS? THANK YOU!