PERFORATING MULTIPLE STRINGS OF CASING: GETTING THROUGH THE OVERLAP ZONE

George E. King
Amoco Production Research

ABSTRACT

Perforating through multiple strings of casing is one of the most difficult design problems in recompletions. The overlap of casing sections may occur in the middle of a series of pay zones as the result of drilling breaks, hole problems or pressure control.

Tests in surface targets have provided information that is useful in design for perforating two and three strings of casing as well as addressing problems of perforating in large diameter casing and the thick cement sections of hole wash-outs.

In the surface tests, large deep penetrating charges in large diameter guns with minimum gun-casing clearance were found to create the most consistent penetration through multiple strings of casing. Information presented includes evaluation of deep penetrating and big hole charges, charge variances, perforation plugging by debris, and effect of clearance on penetration. Entrance hole information in each string is presented on some targets.

INTRODUCTION

Regardless of the care used in designing the casing string, there are always applications where multiple strings of casing are cemented across a pay zone. Most of these sections are overlap areas in the normal progression of an intermediate string to a production string or liner. Perforating through multiple strings of pipe has always offered challenges to any type of perforating process. In this paper, the results of a surface target study are presented in which concentric casing string targets were used to evaluate various charges and perforating techniques.

TEST DESCRIPTION

The surface targets used in the test are composed of dual and triple strings of casing cemented in 60-inch diameter concrete targets. An example of the target construction is shown after firing in Figure 1. The inner strings of casing are either cemented or allowed to hang free, depending on the conditions of the tests. The outer strings are firmly cemented in the

target. The casing used in the test is K-55 or N-80. The charges and guns used for the perforating are from five perforating manufacturers and were purchased from a warehouse just prior to the test. Both deep penetration (DP) and big hole (BH) charges are used in the test. Penetration reported in the cement target is measured from the outside of the last casing string. Entrance hole size of the major and minor axis of the perforation are reported under the heading of "entrance hole."

The charges used in the study were obtained from lots of charges six months old to five years old, stored in a cool, dry environment. The guns used in the test include both screw-type port plug guns (reusable) and scallop guns.

DISCUSSION OF RESULTS

In the studies on two-string targets where the outer string was just slightly larger than the inner string, a small charge in a 2-inch scallop gun with 0^{o} phasing, decentralized for minimum clearance, provided penetration into the cement of from 6.5 to 9.5 inches as shown in Table 1. Although the penetration may seem adequate, the compressive strength of the cement was approximately 2200 psi, or about one-third to one-sixth the compressive strength of a moderately hard sandstone or an average dolomite. When the penetration is discounted for the effects of increased compressive strength, the penetration into the formation may be too short to effectively contact the reservoir. Perforating in a washout section would also create a problem for the small charges. Comparing the results in Table 1 to the results for larger guns in triple-string targets of Table 2 illustrates the increased penetration of 16 to 23 inches available from the larger guns and larger charges. Note that entrance hole sizes in the casing for the test in Table 2 decrease from the inner string to the outer string.[1,2] Photos of the reduced hole size are shown in Figure 2. The large entrance hole produced by the 19 gram big-hole charge is only evident in the inner string while the outer string entrance holes are smaller and penetration is short. The 22 gram charge is a deep penetrator design that produces a smaller, more consistent hole size and extended penetration in the cement target.

Penetration through a multiple string target where the outer casing is very large is shown in Tables 3 and 4. The inner string of casing in these tests is hanging free rather than cemented in place. Using both large and moderate gun sizes in this test shows marginally acceptable penetration for the large charges and large guns, and very short or no penetration for the 10 to 14 gram charges from a 3-1/8-inch gun. The size of the outer string perforations is very small and would create a screenout on almost any frac job. Photographic detail of the perf sizes is contained in Figure 3. Clearance distance between the gun and the casing wall is a major factor with the smaller guns, especially in larger casing. The variation in penetration in the charges shows that the maximum clearance (every third shot) produces the worst performance. Extending this work to a decentralized 3-1/8-inch gun in a 13-3/8-inch single-string target produced penetration of 16 inch concrete penetration (0.33-inch entrance hole) on the minimum clearance size, and 3.5-inch penetration (0.18-inch entrance hole) on the maximum clearance size.

Testing the wrapped metal liner charge produces an 11-inch penetration as shown in Table 2; however, the solid body liner forms a slug or carrot that is trapped in the center string, Figure 4, after the perforation is created. Several of these WML deep penetrating charges were used in tests for comparison with powdered metal liner DP charges and the carrots from the WMLs were always a perf-blocking threat. The carrot produced by these wrapped metal liner charges trails the perforating tip of the explosive and does not make a contribution to penetration. The powdered metal liner charges do not produce carrots and show no evidence of perf blocking in these tests.

CONCLUSIONS

1. The most efficient charges for perforating multiple casing strings are large explosive weight, powdered metal liner, deep penetrating charges contained in the largest gun that can be run in the casing.

2. Entrance hole decreases rapidly as successive casing strings are penetrated by the same jet.

3. Wrapped metal liner charges produce solid carrots of copper which frequently obstruct the perforation and were often found in the entrance holes of one of the multiple strings.

4. Big hole charges were less efficient than deep penetrating charges in creating penetration beyond the outer casing in multiple string targets.

REFERENCES

1. King, G. E.; Bingham, M. D.; Kidder, R. W.: "Factors Affecting Perforating Charge Performance and Relationship to Port Plug Condition." SPE Prod. Eng., Sept., 1986, pp. 379-387.

2. Regalbuto, J. A.; Leidel, D. J.; Sumner, C. R.: "Perforator Performance in High Strength Casing and Multiple Strings of Casing." API, 1983 Pacific Coast Mtg., Bakersfield, Nov. 8-10, 1983.

Table 1

2" GUN 0 DEG PHASED, MINIMUM CLEARANCE
DUAL STRING TARGET
5.5"(14LB) - 7"(23LB) WITH COLLAR ON 7"

CSG	POSITION	WT	LINER TYPE	CHARGE TYPE	CSG HOLE (INCHES)	PEN IN CMT (INCHES)	
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.279 0.287	8.5	
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.282 0.283	7.0	
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.280 0.283	7.5	
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.285 0.285	9.5	
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.215 0.227	6.5	TC
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.238 0.240	7.0	TC
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.222 0.224	6.5	TC
5.5	INNER	6.5	PML	DP			
7.0	OUTER				0.251 0.251	7.0	

TC = THROUGH COLLAR

PML = POWDERED METAL LINER
DP = DEEP PENETRATING CHARGE

Table 2

4" DIAMETER SCREW PORT CASING GUN
CONCENTRIC STRING TARGET 5.5" - 7" - 8-5/8"

CSG	POSITION	WT	LINER TYPE	CHARGE TYPE	CSG HOLE (INCHES)	PEN IN CMT (INCHES)
5.5	INNER	19	WML	DP	0.425 0.402	
7.0	CENTER				0.281 0.419	
8.6	OUTER				0.267 0.250	11"
5.5	INNER	19	WML	BH	0.664 0.605	
7.0	CENTER				0.387 0.386	
8.6	OUTER				0.360 0.358	5"
5.5	INNER	19	PML	DP	0.448 0.586	
7.0	CENTER				0.271 0.266	
8.6	OUTER				0.257 0.266	16"
5.5	INNER	19	PML	DP	0.399 0.402	
7.0	CENTER				0.283 0.265	
8.6	OUTER				0.278 0.278	16"
5.5	INNER	22	PML	DP	0.400 0.412	
7.0	CENTER				0.392 0.385	
8.6	OUTER				0.316 0.318	23"
5.5	INNER	22	PML	DP	0.485 0.533	
7.0	CENTER				0.357 0.428	
8.6	OUTER				0.285 0.320	22"
5.5	INNER	22	PML	DP	0.342 0.355	
7.0	CENTER				0.350 0.309	
8.6	OUTER				0.361 0.350	22"

WML = WRAPPED METAL LINER
PML = POWDERED METAL LINER
DP = DEEP PENETRATING CHARGE
BH = BIG HOLE CHARGE

Table 3

3-1/8" DIAMETER SCREW PORT CASING GUN
CONCENTRIC STRING TARGET 5.5" - 9-5/8" - 13-3/8"
THE 5.5" IS HANGING FREE (NOT CEMENTED)

CSG	POSITION	WT	LINER TYPE	CHARGE TYPE	CSG HOLE (INCHES)		PEN IN CMT (INCHES)
5.5	INNER	20.5	PML	DP	0.391	0.391	
9.6	CENTER						
13.3	OUTER						10"
5.5	INNER	20.5	PML	DP	0.406	0.391	
9.6	CENTER						
13.3	OUTER						9.5"
5.5	INNER	22	PML	DP	0.391	0.406	
9.6	CENTER						
13.3	OUTER						10"
5.5	INNER	22	PML	DP	0.359	0.375	
9.6	CENTER						
13.3	OUTER						4.75"
5.5	INNER	19	PML	DP	0.438	0.375	
9.6	CENTER						
13.3	OUTER						5.5"
5.5	INNER	19	PML	DP	0.422	0.391	
9.6	CENTER						
13.3	OUTER						6.75"

Table 4

3-1/8" DIAMETER SCREW PORT CASING GUN
CONCENTRIC STRING TARGET 5.5" - 9-5/8" - 13-3/8"
THE 5.5" IS HANGING FREE (NOT CEMENTED)

CSG	POSITION	WT	LINER TYPE	CHARGE TYPE	CSG HOLE (INCHES)		PEN IN CMT (INCHES)
5.5	INNER	10.5	PML	DP	0.341	0.314	
9.6	CENTER						
13.6	OUTER				0.160	0.141	3.5"
5.5	INNER	10	PML	DP	0.259	0.257	
9.6	CENTER						
13.6	OUTER				0.132	0.141	2.5"
5.5	INNER	10	PML	DP	0.366	0.364	
9.6	CENTER						
13.6	OUTER				0.150	0.161	1.75"
5.5	INNER	10	PML	DP	0.291	0.283	
9.6	CENTER						
13.6	OUTER				0.162	0.173	2.0"
5.5	INNER	10	PML	DP	0.253	0.257	
9.6	CENTER						
13.6	OUTER				0.196	0.190	2.5"
5.5	INNER	12	PML	DP	0.313	0.372	
9.6	CENTER						
13.6	OUTER						NO PENETRATION
5.5	INNER	12	PML	DP	0.246	0.294	
9.6	CENTER						
13.6	OUTER				0.150	0.129	3.5"
5.5	INNER	12	PML	DP	0.225	0.230	
9.6	CENTER						
13.6	OUTER				0.162	0.168	1.5"
5.5	INNER	12	PML	DP	0.222	0.220	
9.6	CENTER						
13.6	OUTER						NO PENETRATION

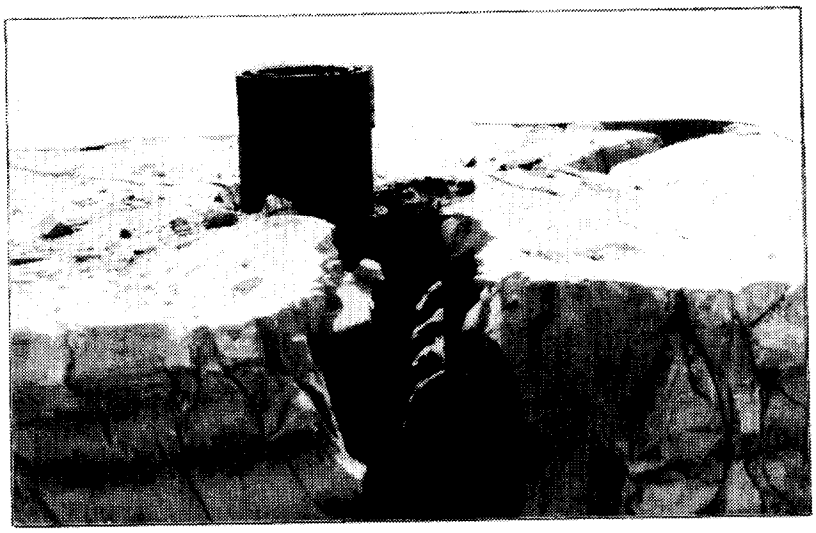

Figure 1 — A three-casing-string target after firing

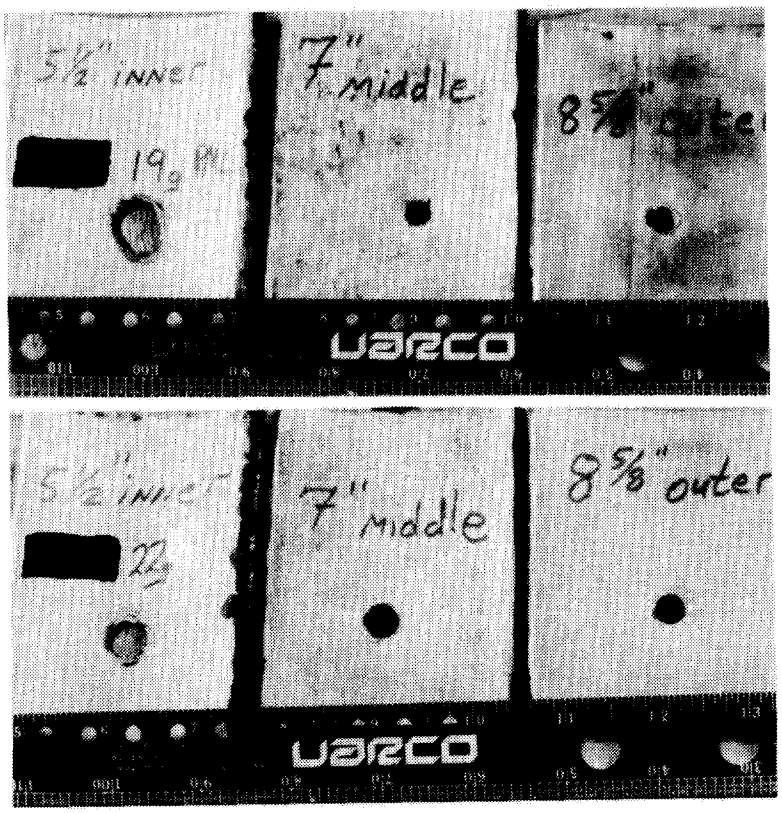

Figure 2 — Examples of penetration through multiple casing strings

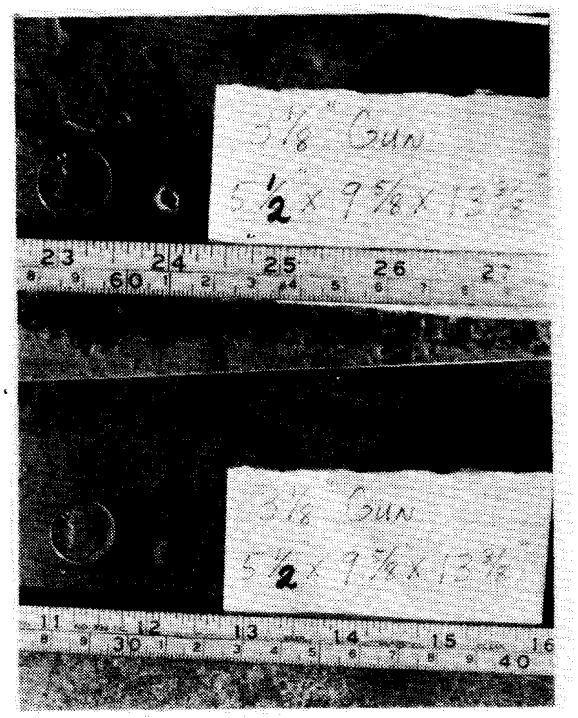

Figure 3 — Results of using a small gun in a three-string target with a large outer casing

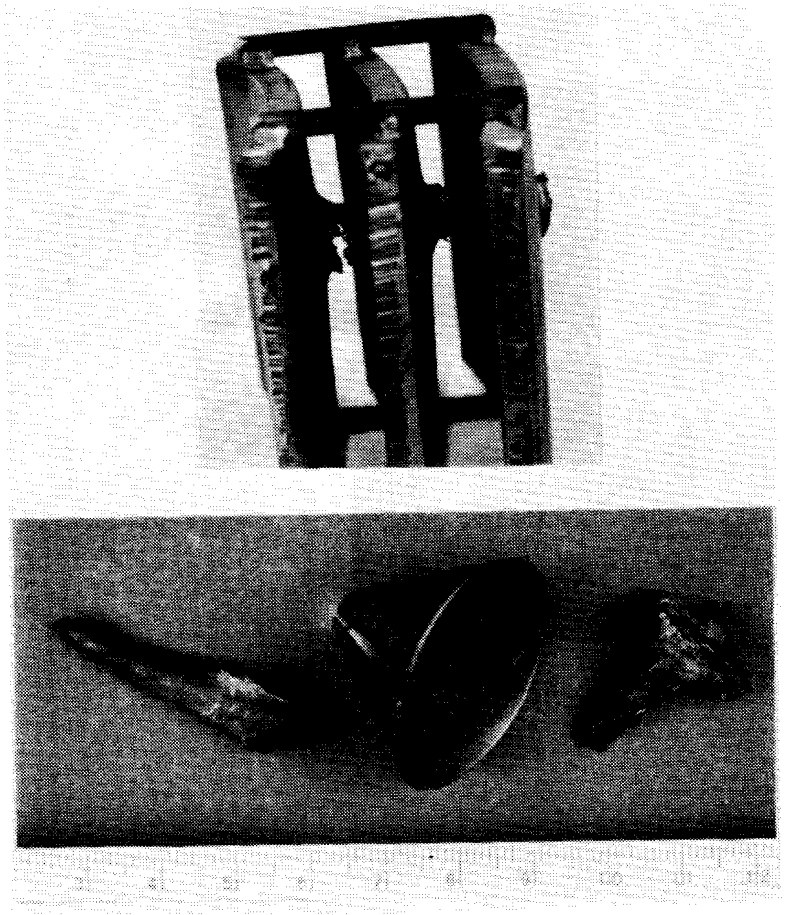

Figure 4 — Top: Carrot plugging the hole in the center string of a three-string target. Bottom: Examples of carrots produced by a wrapped metal liner charge