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Memorandum

To: Mr. Mike Marsh, USEPA

From: Chet Myers, Apex Companies, LLC

Date: July 17, 2013

Re: Analysis of Time of Integration Associated with Blast Impulse Calculation from JASCO Report

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Mike, as you know, EPA has requested additional information in association with blasting and, more specifically, the blast modeling completed by JASCO Applied Sciences (JASCO). Enclosed, please find additional information generated by Apex through discussions with JASCO and via analysis of the JASCO report, as well as papers cited within it. Please also accept this memo as a formal modification to my 7/10/13, 6:27 pm email to your team entitled "NBH-NMFS call and modeling info." While the numerical results discussed in that email led to the same conclusions I will present here, you will find that I have corrected and clarified the method by which they are calculated.

Applicability of Model to Multiple Delayed Explosions and Recommendation For Delay Timing

Explosive use is typically applied with respect to charge weight limits "per delay" rather than "per shot". In production blasting for the purposes of rock removal over large areas, each shot typically contains several delays which are timed in a manner that the resulting waterborne pressures and impulses affecting fish are not considered to be additive. It is our understanding that a common industry and regulatory standard for such delays is approximately 25 milliseconds.

For the purposes of the model produced by JASCO, the controlling "peak pressure" and "peak impulse" used as a basis of comparison were 75.6 psi and 18.4 psi-msec, respectively. These limits were derived from experimental results generated (and forwarded to Apex prior to the start of modeling in 2012) by NMFS. NMFS indicated that if the "peak pressure" and "peak impulse" of the charges could be kept below these factors, then there should be no injury and/or mortality outside of the area of impact.

EPA has requested written confirmation that the model produced by JASCO is applicable to a "charge per delay" use of explosives. As Attachment 1 to this memo, please find a letter from

SDMS Doc ID 548594

JASCO confirming that the modeling conducted by JASCO for their report is applicable to "charge weights per delay for delays of 25 ms or greater." JASCO notes that the pressure waves in question generally have lengths of less than a few milliseconds, and recommends the 25 millisecond criterion as a well established regulatory limit broadly applicable to a variety of blasting situations. Note that NMFS also used 25 millisecond delays in their study.

Mathematical Questions

EPA has also requested an analysis of the mathematics cited within the JASCO report, particularly with reference to the derivation of Impulse, and the time period via which Impulse is calculated (which would then help confirm whether 25 milliseconds was, in fact, a reasonable time period for delay).

The JASCO report cites a 2003 report by Dzwileski and Fenton, whose calculations are taken from the empirical similitude equations presented in Swisdak et al. (1978). It is our understanding that the similitude equations in the Swisdak report formed the basis for JASCO's calculation of peak pressure and peak impulse. Since the equations in the Swisdak report are based on charges detonated in water, it was necessary for JASCO to modify the inputs to these equations in order to account for the fact that the charges at the NBMCT will be detonated inside of bore holes that are highly confined by the surrounding bedrock. JASCO references the Dzwileski and Fenton report in order to determine a "coupling efficiency" consistent with the highly confined condition of the charges.

While the JASCO report implicitly conforms to the 25 millisecond delays referenced in their letter (Attachment 1), it is possible to study the impulse integration period explicitly according to the similitude equations presented by Swisdak. Swisdak presents equations for peak pressure, peak impulse, time constant and energy flux. Of interest here is the Time Constant, Θ, and its relationship to the impulse integration period. For peak pressure and peak impulse, JASCO used the Swisdak equations and constants for the explosive pentolite. These are presented below for consistency along with the Time Constant, Θ, according to Swisdak. They are also included in Attachment 2 as the calculation sheet that we discussed yesterday by phone.

Peak Pressure:

$$P_{pk} = K_1 \cdot (W^{1/3} / R)^{\alpha_1}$$

Where:

- K_1 and α_1 are both constants related to the type of explosive utilized (however, these constants are different than those noted in the Time Constant equation noted below)
- W is the effective weight of explosive utilized in kilograms.
- And R is the "slant distance" (the hypotenuse of a triangle created by both the vertical and horizontal distance from the explosion, for the point under consideration).

Time Constant:

$\Theta = K_2 \cdot W^{1/3} \cdot (W^{1/3}/ R)^{\alpha 2}$

Where:

- K_2 and α_2 are both constants related to the type of explosive utilized (however, these constants are different than those noted in the Peak Pressure equation noted above).
- W is the weight of explosive utilized in kilograms.
- And R is the "slant distance".

$I(r) = K_3 \cdot W^{1/3} \cdot (W^{1/3}/ R)^{\alpha 3}$

Where:

- K_3 and α_3 are both constants related to the type of explosive utilized (however, these constants are different than those noted in the Peak Pressure and Time Constant equations noted above).
- W is the weight of explosive utilized in kilograms.
- And R is the "slant distance".

For pentolite, the following table reflects the values of the two constants for each of the three equations:

Equation	K	α
Peak Pressure	56.5	1.14
Time Constant	0.084	-0.23
Impulse	5.73	0.91

In order to calculate the effective weight of a charge surrounded by highly confined rock, JASCO used the Dzwileski and Fenton modification to the Swisdak equations. This modification calculates a coupling efficiency that can be used to determine the "effective weight" of a given charge. In order to calculate this coupling efficiency, JASCO modeled the rock as an equivalent steel pipe pile, 24 inches in diameter with a 1 inch wall thickness (pp. 22-23 of the JASCO report). The coupling efficiency equation is as follows:

Explosive Coupling Efficiency (%) = $34.37 + 0.005 \cdot p$

Where:

- p is the "pile parameter", further defined in the following equation:

$p = w \cdot d/ t$

Where:

- w = explosive weight in pounds.
- d = pile diameter in inches
- t = wall thickness in inches

Explosive Coupling Efficiency (%) = 34.37 + 0.005 · 50 · 24 / 1 = 40.37 %

The effective weight of a 50 lb charge is therefore: 50 lbs · 0.4037 = 20.185 lbs = 9.175 kg

Peak Pressure would be calculated by inserting the following values (for a 50 pound charge at the radius of influence shown on JASCO's maps):

- For K_1, 56.5
- For, α_1, 1.14
- For W, 9.175 kg
- For R, 127.4 meters (418 feet as shown on Figure 18 and Table 6 of the JASCO Report).

The calculated Peak Pressure is: 0.521 MPa, which converts to 75.6 psi.

Impulse would be calculated by inserting the following values (for a 50 pound charge at the radius of influence shown on JASCO's maps):

- For K_3, 5.73
- For, α_3, 0.91
- For W, 9.175 kg
- For R, 310 meters (1017 feet as shown on Figure 19 and Table 6 of the JASCO Report).

The calculated Impulse is: 0.1268 kPa-sec, which converts to 18.4 psi-msec.

The Time Constant is calculated by inserting the following values:

- For K_2, 0.084 (see table above)
- For α_2, -0.23
- For W, 9.175 kg
- For R, 127.4 meters and 310 meters (to see which is more conservative).

The result is that for 127.4 meters, the Time Constant is: 0.452 ms and for 310 meters, the Time Constant is: 0.554 ms, which are extremely similar. According to Swisdak as well as Dzwileski and Fenton the integration time period for Impulse, τ, is typically some multiple of Θ (Theta) – typically 5 or 6.7 times Θ. Therefore, the maximum value for the integration time period for a 50 pound explosion would be:

6.7 · 0.554 ms = 3.7 milliseconds,

which amounts to 15% of the 25 millisecond value referenced by JASCO in their letter.

ATTACHMENT 1

ATTACHMENT 2