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A REVIEW OF MODELLING AS A TOOL IN CHARGE-GUN PERFORMANCE AND CASING DAMAGE STUDIES

by

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ABSTRACT

It is general knowledge and acceptance that modelling is one of the methods for finding solutions to real problem, particularly complex engineering problems. This paper reviews the idea of modelling as a tool in the charge-gun performance and casing damage studies, and discusses the basic concept of modelling. From the literature survey, it can be seen that charge-gun performance studies have been performed using physical or laboratory modelling, but casing damage studies have been accomplished by laboratory modelling and finite element method.

INTRODUCTION

In general terms, a model is a system or process similar to an original and can be used to predict the relative significance of parameters and the foreseeable behaviour of the original system or problem, so that its performance, efficiency and reliability can be improved and optimized. In other words, modelling is the replacement of one phenomenon by another, in order to study the original phenomenon more conveniently and/or accurately. A model may take mathematical, physical or analogues forms and each model must be tested for reliability and range of application.

Generally, the modelling of a system as an aid to improved and optimized design is a rapidly growing area in all aspect of life, including engineering aspect, such as charge-gun performance and casing damage studies.

BASIC CONCEPT OF MODELLING

Requirement For Model

In general, the development of modelling can be divided into three stages (Ervin, 1980). In the first stage, models are used to study deficiencies in equipment and means to eliminate them, where modelling is regarded as a "scientific toy". Here, the engineer is initially surrounded by uncertainty and is expected to prove the model's usefulness. In the second stage, the advantages of the method or system are generally admitted and the model is used as a preliminary check on new designs and to solve direct problems. In the third stage, the model is used to refine the design, to verify the hypothesis or to study the consequences of interfering with the system in operation. Sometimes modelling is extended to indirect problems. Therefore, by means of the model, the optimal operating parameters of a system or problem can be established in a short time. If a reliable model can be found and tested then there is a valuable aid to solving the problem and other real parameters may also be examined.

Concept of Modelling

The aim of modelling as a tool in engineering is to enable as many aspects of a system to be studied without recourse to the real system. In general, the process of modelling involves three interrelated phases: 1) define the important parameters in the problems or system, their expected influence and the relationship between them, 2) solving for the relationship and influence of the known or design parameters on the desired consequences; 3) to test the solution from second phase for reliability and range of application.

The first phase primarily consists of recognizing the nature fo the problem or system to allow it to be defined by existing theory. The majority of engineering problems are usually an extension or improvement of an established theory, method or fact (Davies, 1984).

The second phase involves determination of the relationship between relevant parameters and their effects on the system performance. It may lead to the solution of the problems. The solution may be justified by mathematical relationship, physical reasoning or both.

The final phase is to test and validate the model. This assessment process can be accomplished by comparison of the solution of different modelling techniques or solution procedures, and by comparison of the real system, if experimental or field data are available. Perfect agreement can never be secured, and mathematical techniques are often used to correlate observed results with the theoretical predictions.

According to Szucs (Szucs, 1980), there are three modelling concepts: i.e., mathematical, computation and physical. The mathematical model describes the intrinsic behaviour and the uniquity conditions of a system studied, in the form of a mathematical relationship among physical variables.; i.e., generally in the form of differential equations.

A computation model is a system of algebraic relationships based on the mathematical model or one of its transform, directly suitable for the performance of numerical calculations. The operations prescribed by the computational model are most often programmed for a computer. This procedure is sometimes termed as a numerical modelling.

The physical model is an experimental setup suitable for adjusting and measuring parameters defined by a similitude transformation of the mathematical model. The phenomena taking place in the model and in the original system are similar under some well defined conditions. Physical modelling is a procedure by which the original system or phenomenon is replaced by a similar model system, and model phenomena are studied to infer phenomena taking place in the original system. The modelling procedure allows scale changing, use of different working media and even replacement of phenomena by analogy. The results from physical modelling can be used to test and validate the mathematical modelling. The physical model solution can be tested and validated by comparing with the actual field data.

Method of Solution

Generally, there are three types of problems solving method; i.e., analytical, numerical and experimental (Szucs, 1980). The general outline of the methods are presented in Table 1.

The analytical approach involves solving the mathematical equation under given uniquity conditions, so that the mathematical relationship between unknown parameters and known parameters can be established. In a numerical method, the differentiation and/or integration of the mathematical equations is replaced by algebric operations, and the approximate solution is obtained as a results of those operations. The adequacy of solution depends on the reliability of the basic mathematical model and the discrete fineness of the model. One of the most widely used numerical modelling technique is the finite element method (Davies, 1984).

The experimental solution is based on an experiment; i.e., testing by equipment or physical modelling. Here, the mathematical statistics plays an important role in the planning of measurement programmes, in the control and optimization of measurement runs, and in evaluating the results. The experimental setup and the model size depend on the means and time available, accessibility and availability of the equipment and material, and the nature of the parameters to be measured. The model must not be so small that the phenomenon is influenced significantly by the process of measurement. On the other hand, it must not be so large that any auxiliary requirements cannot be fulfilled.

Table 1
Summary of the Outline of the Problems Solving Method

STEP	SOLUTION METHOD		
	ANALYTICAL	NUMERICAL	EXPERIMENTAL
1	Verbal formulation of the problem		
2	Formulation of a mathematical problem		
3	Transformation and/or simplification to a form amenable to solution	Discretization of the model	Transformation of the mathematical model into a physical model
4	Establishing the succesion of steps leading to a solution	Compilation of algorithms and composition of the block diagram	Drawing up an experimental program and setup
5	Establishing the relationships representing the solution of the mathematical model	Writing and running the computer programme	Conducting and evaluation of the experiments. Establishing the relationship between parameters
6	Test of the solution		

REVIEW OF CHARGE-GUN PERFORMANCE AND CASING DAMAGE MODELLING

Due to the nature and complexity of the charge and gun performance and their effect to the casing damage during perforating process and its related problems in actual conditions, the studies are generally accomplished by means of modelling. As can be seen from Table 2, modelling of the charge and gun and their effect to the casing damage had been accomplished by the physical modelling with all forms of solution; i.e., analytical, numerical or experimental.

Table 2
Summary of Charge-Gun & Casing Damage Studies

INVESTIGATORS	MODEL FORM	RESEARCH AREA
Thompson	Laboratory	Casing & gun performance
Weeks	Laboratory	Casing & gun performance
Saucier	Laboratory	Casing & gun performance
King	Laboratory	Casing & gun performance
Halleck	Laboratory	Casing & gun performance
Bell	Laboratory	Casing damage
Smith	Finite element modelling	Casing damage

Charge and Gun Performance Modelling

Charge and gun performance appear to be one of the important factors that affect the productivity of perforated wells. In order to quantify the effectiveness of a charge and gun, it is desirable to simulate the real downhole shooting conditions.
Thompson (Thompson, 1962), carried out laboratory experiments to study the effect of formation compressive strength on gun performance by using an actual formation rock, under simulated conditions. The experimental results showed that gun penetration depth decreases as the compressive strength increases, depending on the gun type ; i.e. the effect becomes greater for bullet guns than for jet guns or hydraulic perforators. In addition, he also showed that there is a relationship between penetration depth and formation compressive strength.

Based on the results from test-well shooting in the laboratory, Weeks (Weeks, 1974) agreed with Thompson and also showed that larger charges give better entrance hole size and penetration depth than the smaller charges.

Saucier et.al. (Saucier, 1980) performing laboratory experiments using formation core samples showed that the penetration depth into stressed Berea sandstone and Wasson dolomite are initially reduced with increasing effective stress until a penetration plateau is achieved. Within the same formation type, there is no correlation between the penetration depth and compressive strength, but between different formation, they agreed with the previous finding, i.e. penetration depth decreases as the compressive strength increases. However, they concluded that compressive strength alone is not considered a reliable basis for downhole penetration depth estimation, which is not in agreement with Thompson. In general, the experimental results also showed that penetration depth in the downhole models are less than that in Standard API RP 43, section II test data.

From laboratory experiments using centralized and decentralized guns in large cement targets, King et.al.(King, 1986) showed that the larger charges performed better especially in the multiple strings or in casing with the diameter equal or greater than 7 in., where maximum clearance is greater than 2 in. Wrapped metal liner charges produce less penetration depth than powdered metal liner charges. Debris from the gun and charge appears to be a serious plugging problem, particularly in multiple strings completion. Their experimentals also showed that charges manufactured in more than three years produce variation in penetration depth and many shots are less than 50 % of the API RP 43 prediction. On the other hand, charges manufactured within three years have performed satisfactorily. Misaligment or malfunction charges produce 20 % to 50 % less penetration depth than those produced by properly aligned or properly functioning charges.

Based on laboratory experiments using large blocks of Berea sandstone and Bedford limestone with multishot perforating guns and three different types of charge, Halleck et.al.(Halleck, 1988) confirmed that penetration depth reduction depends on charge design, size and rock type. Different stress magnitudes that caused penetration depth reduction are generally because of the different in stress intensity produced by the charges, depending on the rock type. The penetration depth in Bedford limestone is less sensitive to the stress then that in Berea sandstone. They also agreed with Saucier et.al. (Saucier, 1980) that downhole penetration depth knowledge is insufficient for estimating perforated well productivity.

Perforated Casing Damage Modelling

One of the major concerns in designing charge, gun and perforating jobs is casing damage. In order to investigate and analyze the major factors influencing casing damage, Bell et.al. (Bell, 1980) carried out laboratory experiments using two types of casing (J-55 and N-80) of various size and weight, together with various cement thickness and three basic types of gun. The results generally showed that casing damage depends on gun type, casing material and degree of support, hydrostatic pressure, amount of explosive load and clearance. The hollow carrier steel shaped charge guns produce no casing damage except swelling and erosion of the casing on the opposite side of the maximum explosive concentration. The bullet guns appear to cause little casing damage, primarily in hard rock. On the other hand, the expendable capsule guns can produce casing damage. The degree of damage will decrease with increasing casing wall thickness, yield strength, cement thickness, degree of support, clearance and hydrostatic pressure, but the damage will increase as the explosive load increases.

Perforated casing may collapse because of loss of cross-sectional integrity due to increasing of external fluid pressure or excessive stress associated with the formation flow. In conjuction with this problem, Smith et.al. (Pattillo, 1983) developed a mathematical model using finite element method to investigate the collapse of perforated casing. The results showed that the spiral pattern was significantly stronger than the inline pattern which together with small amounts of sand production will drastically reduce the casing collapse integrity. For lower shot densities, the primary influence of the perforation pattern on casing collapse integrity is the creation of a non-uniform load distribution around the perforation.

They also performed finite element modelling based on poroelastic-plastic material properties by which the results had been verified with the results from experimental work. From these studies, they concluded that without the formation production, reduction in casing collapse integrity is directly related to the existence of the perforation, not because of the formation response to the pressure differential within the system. The small amount of formation production will drastically reduce the perforated casing integrity, particularly for the structure with greater shot density, i.e. greater than 6 shot per foot. (Pattillo, 1985)

CONCLUSION

1. Modelling is one of the methods to enable predictions to be made by simulation of the real system. The model can be in the form of mathematical, computation or physical and the solving method can be analytical, numerical or experimental solution.
2. Many aspects of the charge, gun and casing damage have been modelled using two types of modelling techniques, i.e. by means of laboratory experiments and finite element.
3. The results from mathematical modelling are generally tested and validated with the results from laboratory experiments and/or field data. The results from laboratory experiments are generally tested and validated with field examples. If the laboratory or field data are not available, the results from mathematical modelling are normally tested and validated by comparing the results from different solution techniques.
4. The results from all investigators with different modelling techniques or approach are in agreement and/or become complementary to each other.

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