

Design Through Analysis Applying Limit-State Concepts and Reliability Methods

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ABSTRACT

This paper describes a recent technical innovation in design, called "Design Through Analysis" led by the authors. In the new approach, finite element methods are used to simulate global behavior and detailed structural strength. The global analysis and local analysis are integrated to determine the governing limit-states and optimize the design. The advantage of using such advanced engineering is a substantial reduction of project CAPEX and OPEX.

The paper presents the following technical developments: (1) Design Through Analysis (DTA) concepts, (2) non-linear finite element simulations of global behavior and detailed local strength, (3) limit-state design criteria, (4) vortex-induced vibrations and fatigue (5) design for trawling loads, (6) wall-thickness design based on LCC (Life-Cycle-Cost) optimization, (7) reliability-based calibration of safety factors and inspection planning, (8) design of in-field flowlines.

Keywords: Design-Through-Analysis (DTA), pipeline, HP/HT, buckling, limit state design, reliability design, FEM.

INTRODUCTION

A recent technical revolution in the design process has taken place in the Offshore and Marine industries. Advanced methods and analysis tools allow a more sophisticated approach to design that takes advantage of modern materials and revised design codes supporting limit state concepts and reliability methods. At JP Kenny we call the new approach "Design Through Analysis" where the finite element method is used to simulate global behavior of pipelines as well as detail structural strength. The two-step process is used in a complementary way to determine the governing limit states and to optimize a particular design.

The advantage of using advanced engineering is a substantial reduction of project CAPEX and OPEX by minimizing unnecessary conservatism in the design through a more accurate determination of the effects of local loading conditions on the structure. Rules and design codes have to cover the general design context where there are often many uncertainties in the input parameters and the application of

analysis methods. Where the structure and loading conditions can be accurately modeled, realistic simulations reveal aspects of the design codes, which may be overly conservative for a particular design situation. The FEM (Finite Element Methods) model simulates the true structural behavior and allows specific mitigating measures to be applied and can document their effects.

Better quality control in pipeline production allow more accurate modeling of material while FEM analysis tools allow the engineer to simulate the through-life behavior of the entire pipeline system and identify the most loaded sections or components. These are integrated into a detailed FEM model to determine the governing failure mode and limit criteria which is compared to the design codes to determine where there is room for optimization. The uncertainties in the input data and responses can be modeled with the help of statistics to determine the probability distributions for a range of loads and effects. The reliability approach to design decisions can then be applied to optimize and document the fitness for purpose of the final product.

DESIGN THROUGH ANALYSIS (DTA)

Engineers have long struggled with analytical methods, which only consider parts of the structural systems they are designing. How the different parts affect each other and, above all, how the structural system will respond to loading near its limiting capacity requires a non-linear model which accurately represents the loads, material and structure. The sophisticated non-linear FEM programs and high-speed computers available today allow the designer to achieve numerical results, which agree well with observed behavior and laboratory tests.

The simulation of global response together with local strength is often necessary because design parameters and local environment are project-specific. A sub-sea pipeline is subject to loading conditions related to installation, seabed features, intervention works, testing, various operating conditions and shut-downs which prescribe a load path essential to the accurate modeling of non-linear systems involving plastic deformation and hysteresis effects. For example, simulation can verify that a pipeline system undergoing cyclic loading and displacement is self-stabilizing in a satisfactory way (shakedown) or becomes unstable needing further restraint. The simulation of pipeline behavior in a realistic environment obtained by measurement allows