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# CHAPTER 86

# SOFTWARE FOR RELIABILITY BASED OPTIMIZATION OF PASSIVE FIRE PROTECTION ON OFFSHORE TOPSIDES [1]

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## 1. INTRODUCTION

Fire is one of the major risks of serious damage or total loss of platforms/topsides used for oil and gas production. This paper presents a methodology and software for reliability based, optimisation of the layout of passive fire protection (PFP) of firewalls and on structural members on offshore structures. The paper is based on research performed within the EU supported research project B/E-4359 "*Optimised Fire Safety of Offshore Structures*". The partners in this research project are listed in the acknowledgement. Special emphasis is put on the optimization software developed within the project.

A total optimisation of topside of an offshore structure involves optimisation of the passive fire protection, the active fire protection system, the safety equipment, the primary and secondary structural elements, the Temporary Safe Refuge, and Escape, Evacuation and Rescue Systems.

Since PFP is very important for the safety of offshore structures this section focuses on the optimisation of PFP. The overall optimisation problem formulated is to minimise the cost of the PFP with requirements on the minimum acceptable safety. The design variables are the type and amount of PFP and to some extent whether PFP is to be applied to walls/structural elements or not. Uncertainties are related especially to the fire loading, to the thermal properties of the structural steel and the insulation and to material and strength parameters.

Methodologies for optimisation of PFP and corresponding computer programs

[1] Proceedings IFIP TC7 Conference, Detroit, Michigan, USA, July 1997.

have been developed.

OPTIWALL performs deterministic and reliability-based optimisation of the PFP attached to firewalls. This program determines the optimal thickness and material for the PFP for one or more firewalls subjected to heat loads while minimising the cost.

The program OPTIBEAM performs deterministic and reliability-based optimisation of the PFP attached to structural members (beams or columns). The program determines the optimal thickness (and material) for the PFP for one or more scenarios while minimising the cost of PFP. Additionally, the effect of other mitigation measures such as deluge/sprinkler system can be taken into account. In both programs constraints are related to the reliability of the wall/structural members using limit states on the maximum temperature and on the general buckling/yielding failure using API, AISE, and ECCS models.

## 2. ARCHITECTURE OF THE OPTIMIZATION SYSTEM

A total optimization of the topside of an offshore structure will as mentioned in the introduction include optimization of the passive fire protection and of a number of other systems. However, such a complex optimization is not realistic with the current knowledge in this field. Since PFP is very important for the safety of the topside it was decided to concentrate on optimization of PFP. This choice also has the advantage that it contains all the major aspects related to fire safety. The topside layout is given ( the fire-walls are located and structural elements protected using PFP are identified). The design variables are the amount and type of PFP. The optimization problem is then to minimize the cost of the PFP with requirements on the minimum acceptable safety. Focus is put on PFP optimization, but with the addition that the effect of other mitigation measures can be taken into account when performing the PFP optimization. As an example the effect of deluge/sprinklers' can be included into the optimization.

The optimization methodology consists of number of steps. Not all steps are obligatory.

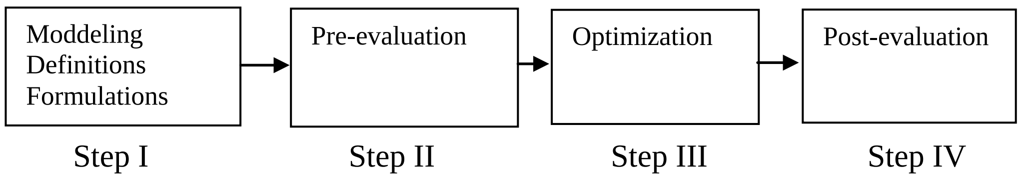


Figure 1. Architecture of the optimization system

## 3. STEP I. MODDELING, DEFINITIONS AND FORMULATION

This first step consists of a number of actions such as:

- selection of the structural model,
- definition of a FEM model,
- grouping of structural elements,
- definition of fire scenarios,
- definition of failure modes and corresponding limit states,
- definition of the stochastic modeling.

## 4. STEP II. PRE-EVALUATION

This pre-evaluation step is very useful. In many cases the optimization of PFP can be performed using only the pre-evaluation modules. In the pre-evaluation:

- a FEM analysis of the structure is performed and the potential failure modes are evaluated,
- the structure is modified if one or more limit states are violated,
- sensitivity analysis parameters are defined,
- a sensitivity analysis is performed to obtain a feasible design without re-analysis of the structure,
- design variables are added or removed based on the results of the sensitivity analysis,
- a corresponding deterministic optimization problem is formulated (optional),
- the deterministic optimization problem is solved,
- the reliability index and its derivatives are calculated so that limit states, stochastic variables etc. may be deleted/added.

## 5. STEP III. OPTIMIZATION

This step is the main step, but in some cases it is not used since it often is very time consuming. In this step:

- the reliability based optimization problem is defined (design variables, objective function and constraints),
- the reliability based optimization problem is solved.

## 6. STEP IV. POST EVALUATION

In this step:

- the optimization results may be modified, e.g. rounding up of some design variables to nearest allowable value,
- the optimization results are evaluated to ensure that all assumptions are valid, a new grouping of elements or the use of new PFP material may be done and a new optimization performed, i.e. the optimization is repeated from the beginning.

## 7. FORMULATION OF THE PROBLEM

The reliability based optimization problem can be formulated in the following way

$$\begin{aligned} &\min_{\bar{b}} C(\bar{b}), \quad \bar{b}^T = (b_1,...,b_n) \\ &s.t. \quad \beta_j(\bar{b},\bar{x},T,s_i) \geq \beta_j^{\min} \; j=1,...,M \\ &\qquad \beta^{sys}(\bar{b},\bar{x},T,s_i) \geq \beta^{sys,\min} \\ &\qquad b_i^{\min} \leq b_i \leq b_i^{\max} \; i=1,...,n \end{aligned} \tag{1}$$

where $C$ is the objective function (cost function) and $\bar{b}^T = (b_1,...,b_n)$ are the design variables. $s_i$ is fire scenario $I$ and $T$ is a reference time. The reference time could be the time where the fire is maximum or the time to evacuate all personnel. $x$ is a vector of stochastic variables, $M$ is the number of constraints and $n$ is the number of design variables. The solution to this problem is $\bar{b}^{i}_{opt}$ where the superscript indicates scenario i. Problem (1) is solved for all $N$ scenarios and as the final optimal solution is used the maximum value for each design variable.

Optimization of PFP is divided into two parts:

- optimization of PFP on non-structural parts (firewalls) using the software package OPTIWALL
- optimization of PFP on structural members using the software package OPTIBEAM,

The programs OPTIWALL and OPTIBEAM are able to find optimal PFP for both firewalls and structural members subjected to pool and jet fires.

## 8. THE SOFTWARE PACKAGE OPTIWALL

The program OPTIWALL combines the fire analysis program RASOS_B (developed by AST), the reliability program RTLS (developed by 1ST) for reliability evaluation of firewalls subjected to fire (consisting of HOTPLATE (developed by CSR) for calculation of heat transfer to firewalls and RELIAB (developed by CSR) for reliability evaluation) and the optimization program OPTIM (developed by CSR)) .

It is assumed that all fire walls have insulation material, that the geometry of the fire wall is constant and that only insulation on the hot side of the firewall is optimized. There are only two design variables for a fire wall namely the thermal conductivity of the PFP material and the thickness of the insulation material.

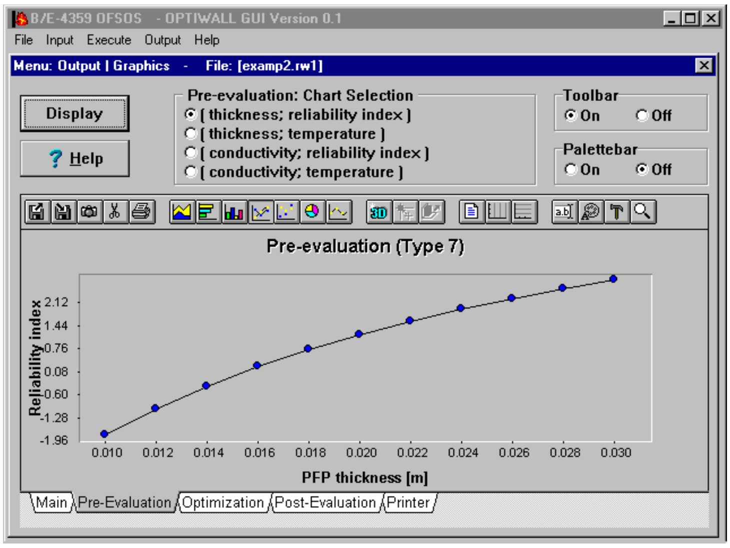


Figure 2. OPTIWALL. Pre-Evaluation: Reliability index as function ofthe PFP thickness.

The objective function is the cost of the PFP modeled as a function of the thickness and of the thermal conductivity and a constant term related to the installation. A constraint is in the deterministic case imposed on the temperature at the interior face of the insulation, which at the reference time T (60 minutes for A60 walls and 90 minutes for A90 walls) must be lower than some specified limit state temperature. In the reliability based formulation the constraints are related to the probability that the temperature in the firewall exceeds a limit value.

In figures 2, 3, and 4 are for illustration shown output screens from OPTIW ALL, namely output from the pre-evaluation and the history of the objective function and the history of design variables.

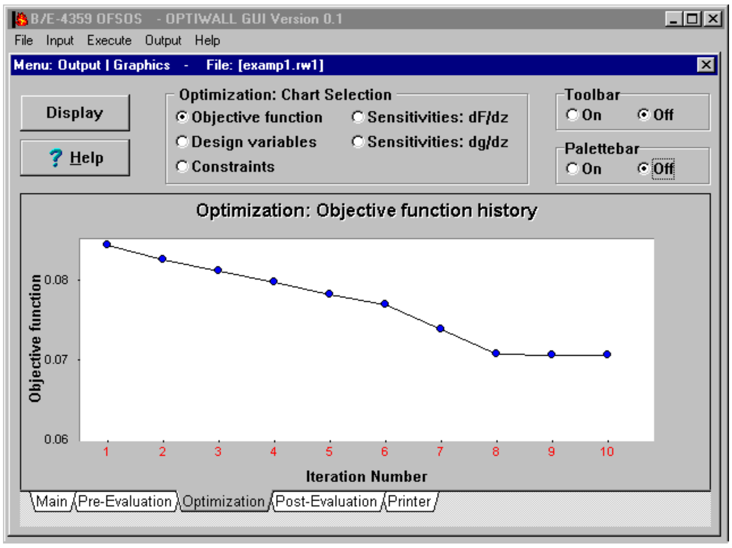


Figure 3. OPTIWALL. Optimization: History of the objective function.

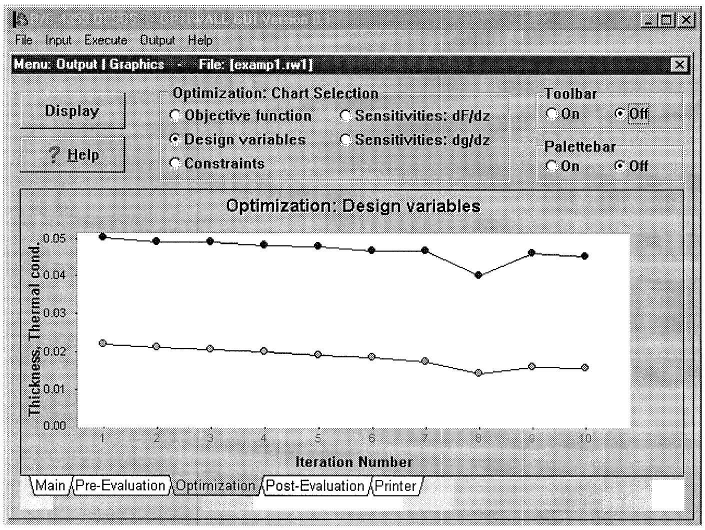


Figure 4. OPTIWALL. Optimization: History of the design variables.

## 9. THE SOFTWARE PACKAGE OPTIBEAM

The OPTIBEAM program combines modules for reliability with modules for optimization. Two modules for reliability assessment of off-shore platforms subjected to fire have been developed: RELCSR (developed by CSR) combining RELIAB and the RASOS limit-state module (developed by AST) and RASOS_R (developed by AST) using the built-in reliability program in RASOS (developed by AST) amended to take into account members subjected to fire.

OPTIBEAM performs deterministic and reliability based optimization of PFP attached to structural members. The design variables are the thickness of the PFP on topside beams/columns. Since the number of structural elements on a standard topside structure may be quite large, grouping the design variables into a number of groups is implemented in OPTIBEAM in order to reduce the number of design variables. In order to take into account the effect of other mitigation measures (AFP, improved lay-out, etc.) a third term may be included in the objective function. The objective function is the sum of the total cost of PFP and the expected failure costs. Constraints are related to limiting temperature failure criteria or to member failure by buckling/yielding (using the API/AISC model or the ECCS model).

In figures 5, 6, and 7 are for illustration shown the output screens from OPTIBEAM, namely output from the pre-evaluation, the history of the objective function, and the history of the design variables.

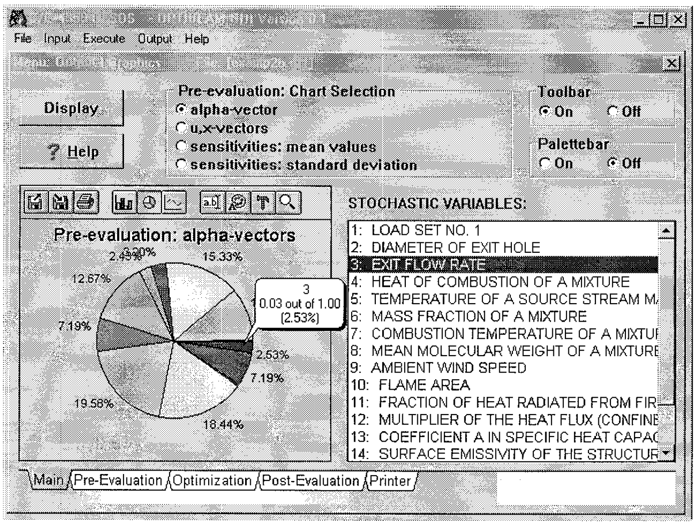


Figure 5. OPTIBEAM. Pre-Evaluation: Sensitivity analysis.

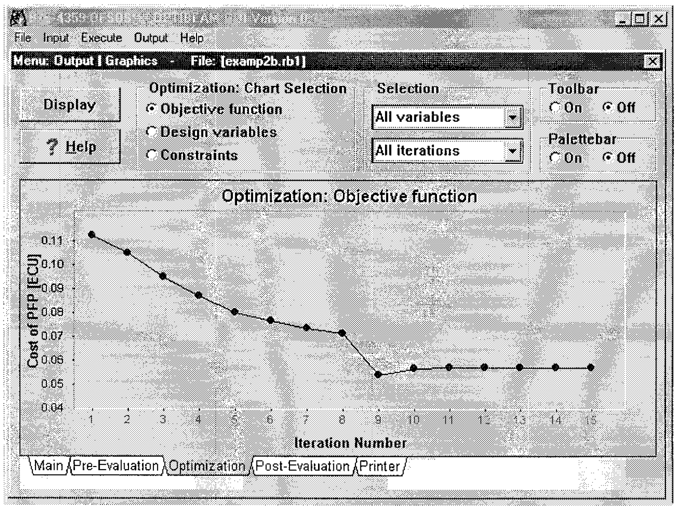


Figure 6. OPTIBEAM. Optimization: History of the objective function.

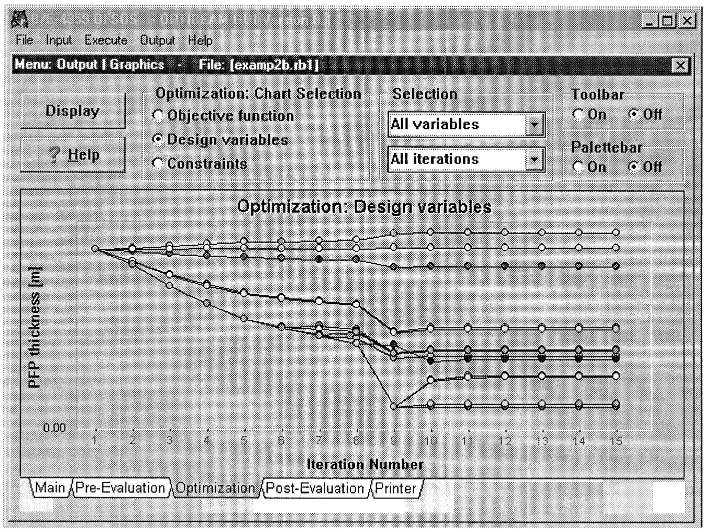


Figure 7. OPTIBEAM. Optimization: History of the design variables.

## 10. CONCLUSIONS

Major achievements in this project with regard to reliability based optimization can be summarized to:

- A formulation of reliability based optimization problems for both PFP on firewalls and structural members have been specified.
- A methodology and specifications for prototype software for PFP optimization including pre- and post-evaluation of firewalls and structural members have been developed.
- A DOS program OPTIWALL for optimization PFP (including pre- and post-evaluation) of PFP on firewalls has been implemented and tested.
- A DOS program OPTIBEAM for optimization PFP (including pre- and post-evaluation) of PFP on structural members has been implemented and tested.
- A Windows GUI for OPTIWALL and OPTIBEAM have been developed.

## 11. ACKNOWLEDGEMENT

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