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Use of Simulation Driven Design for New Product Development

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ABSTRACT: A selective overview of group and individual process behavior of combined suction and discharge cycles of a hypothetical oil refinery plant carrying carbon fiber reinforced plastic pipes is presented and a model is proposed to unify new product development and simulation driven design via tank piping.

Keywords*:* *C*arbon fiber reinforced plastics, new product development, simulation driven design, tank piping.

I. INTRODUCTION

The collaboration of New Product Development (NPD) & Simulation Driven Design (SDD) is done to improve total cycle time & quality of the output in technology driven firms. NPD is a vital phenomenon in engineering design for defining the design problems, gathering information, generating multiple solutions, analyzing & selecting a solution, testing & implementing the solution.

In today's world of leading development & competition, it is highly advisable to go for proper & uniform checklists for design & delivery of the product-to-release in market. For this, the integration of product cycle & simulation is essential. Simulation driven design is used in order to have modeling flexibility & judgment of system's behavior in a controlled environment. SDD also gives new insights of a complex system with possibility to undertake broad experimentation in relatively lesser time & effort. It makes no specific attempt to isolate the relationships between any particular variables.

At present, CFRP is a new and strong material recommended for the manufacturing of Automobile Industry parts. It is a light-weight polymer matrix composite material reinforced with carbon fibers. The reinforcing dispersed phase may be in the form of either continuous or discontinuous carbon fibers of diameter about 0.0004". Carbon fibers possess highest specific (divided by weight) mechanical properties such as modulus of elasticity & strength. They possess good corrosion strength; have high fatigue strength, high strength-to-weight ratio, high modulus of elasticity-to-weight ratio, low coefficient of thermal expansion, high electric conductivity.

Here, the new product is taken as Carbon Fiber Reinforced Plastic (CFRP) material as a pipe material in a hypothetical oil refinery plant and through various simulation steps conducted under the pipe design software i.e. CAESAR- II. It is ensured that the product meets all regulatory requirements and that all required documentation is maintained. The demonstration of the system & the required flow of the working fluid (i.e. Naphtha) is shown via proper steps & stress-strain analysis techniques.

It is a very useful problem-solving technique. CAESAR-II has served its purpose in calculating the critical results & values such as stress, strain, horizontal displacements, vertical displacements, etc. using various desired parameters. The modeling methodology is kept simple & clear in order to neatly define the usage of SDD in NPD without complicating the system variables.

II. LITERATURE REVIEW

In order to study the behaviour of CFRP pipes used in utility piping the literature related to the flexibility analysis, fatigue & failure analysis of the various components of various kinds of systems has been studied. Houssam Toutanji, Sean Dempsey proposed that fiber reinforced polymer composites (FRPC) have established a strong position as an effective mean for the repair and rehabilitation of infrastructure. However, the use of FRP in the repair and rehabilitation of pipelines is a new concept that has the potential to improve the way to repair pipelines. This paper showed the benefits of using FRPC and the profit to provide stress expressions on the interaction between the different stresses exerted on pipe walls and the effects of FRPC sheets on the circumferential stresses of damaged pipe walls. The effects of three different FRPC sheets: Glass FRP (GFRP), Aramid FRP (AFRP), and Carbon FRP (CFRP) on the performance of pipe walls were compared analytically. Results showed that carbon fiber composites perform better than glass or aramid in improving the ultimate internal pressure capacity of pipes and therefore, significantly enhance the strength, durability, and corrosive properties.

Earlier a report was submitted on carbon nanotube polymer composites that reveal the recent advances in CNT composite toughness. Particular interest is also given to interfacial bonding of carbon nanotubes to polymer matrices as it applies to stress transfer from the matrix to the CNT. [1]

A report was proposed fatigue strength of steel girders strengthened with carbon fiber reinforced polymer patch. Fatigue sensitivity details in aging steel girders are leading problems faced by structural engineers. The design characteristics of steel members can be enhanced significantly by epoxy bonding carbon fiber reinforced polymers (CFRP) laminates to the critically stressed tension areas. The study reveals that the CFRP patch not only tends to extend the fatigue life of a detail more than three times, but also decreases the crack growth rate significantly [11].

III. METHODOLOGY

A hypothetical model of an oil refinery plant is generated on Intergraph Caesar II representing system dynamics in terms of suction & discharge lines, pipe supports, pipe material, and conditions of pressure, temperature & loads. CAESAR II follows some specific piping code requirement, i.e. ASME B31.1 or ASME B31.3 or other applicable power or process piping code. A stress analysis report is generated showing basis for analysis, list of load cases, static analysis input listing, stress isometrics, stress report, displacement report & restraint summary.

A process flow diagram is constructed showing the flow of the working fluid in the system.

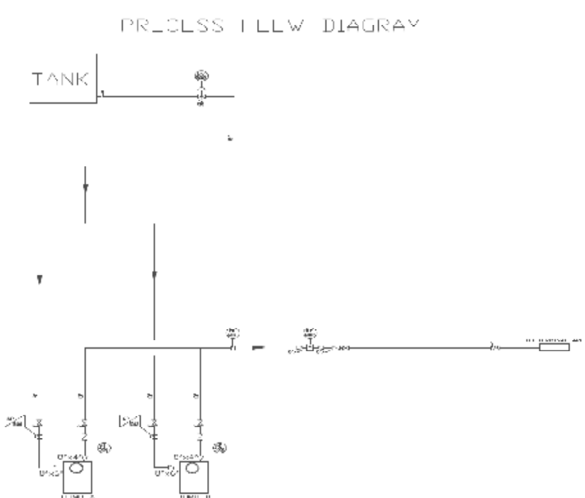

Fig. 1. Process flow diagram.

Various important tests are performed in order to check the efficiency of the system & the impact of the material used for pipe i.e. CFRP.

Stress analysis or Piping stress analysis is one of the most important tests involved which address the static & dynamic loading resulting from the effects of gravity, temperature changes, internal & external pressures, changes in fluid flow rate & seismic activity.

After calculation for basis for static analysis, following points are conceived. Lines are analyzed at operating & design conditions. Allowable loads for static equipment are as per codes. The transverse deflection will be limited to 25mm in general. For supports, default stiffness value of CAESAR II is considered if not otherwise mentioned. The vertical deflection due to sustained loads will be limited to 15mm. The number of thermal load cycles is considered to be 7000.

A load case description is obtained including the restraint summary: loads on restraints.

LOAD CASE DEFINITION KEY
CASE 1 (HYD) WW+HP
CASE 2 (OPE) W+T1+P1
CASE 3 (OPE) W+T2+P1
CASE 4 (OPE) W+T3+P1
CASE 5 (OPE) W+T4+P1
CASE 6 (OPE) W+T5+P2
CASE 7 (OPE) W+D1+T1+P1
CASE 8 (OPE) W+D1+T2+P1
CASE 9 (OPE) W+D1+T3+P1
CASE 10 (OPE) W+D1+T4+P1
CASE 11 (OPE) W+D1+T5+P2
CASE 12 (SUS) W+P1
CASE 13 (SUS) W+P2

Stress isometrics are received for pump suction.

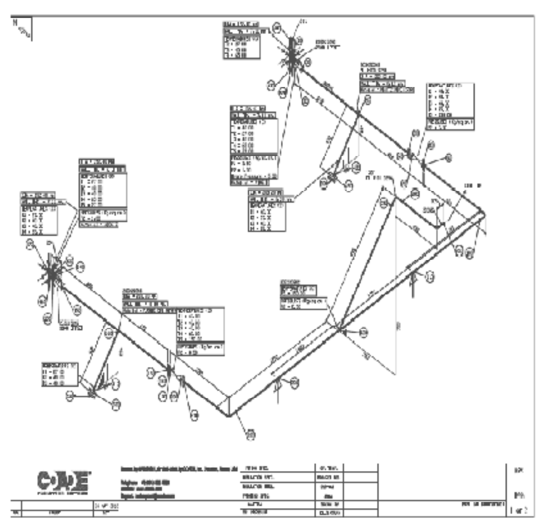

Fig. 2. Stress isometrics for pump suction sheet 1 of 2.

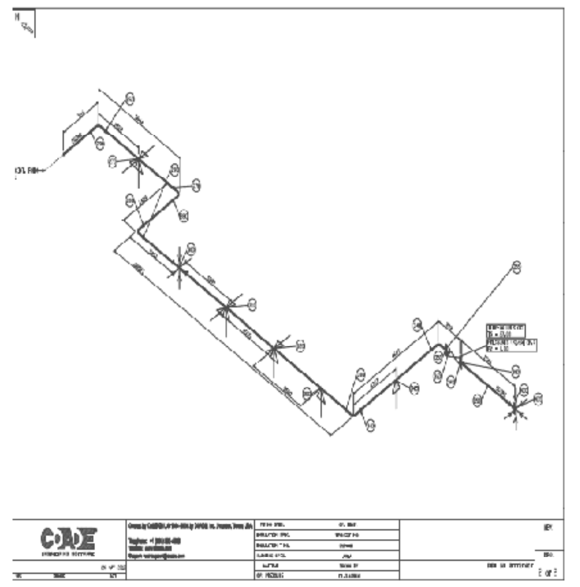

Fig. 3. Stress isometrics for pump suction sheet 2 of 2.

A displacement report is obtained showing the nodal movements on CASE 2 (OPE) W+T1+P1.
Now, the listing of load cases for pump discharge is taken as follows:
CASE 1 (HYD) WW+HP
CASE 2 (OPE) W+T1+P1
CASE 3 (OPE) W+T2+P1
CASE 4 (OPE) W+T3+P1
CASE 5 (OPE) W+T4+P1
CASE 6 (OPE) W+T5+P2
CASE 7 (SUS) W+P1
CASE 8 (SUS) W+P2
CASE 9 (EXP) L9=L2-L7
CASE 10 (EXP) L10=L3-L7
CASE 11 (EXP) L11=L4-L7
CASE 12 (EXP) L12=L5-L7
CASE 13 (EXP) L13=L6-L8

Stress isometrics for pump discharge are taken out.
Stress summary report is obtained showing highest stresses at various loads.
Load case definition key is shown as:
CASE 7 (SUS) W+P1
CASE 8 (SUS) W+P2
CASE 9 (EXP) L9=L2-L7
CASE 10 (EXP) L10=L3-L7
CASE 11 (EXP) L11=L4-L7
CASE 12 (EXP) L12=L5-L7
CASE 13 (EXP) L13=L6-L8
Piping Code: Multiple Codes
BS 7159 = BS 7159 (1989)
The load cases are now considered where code stress check has passed.

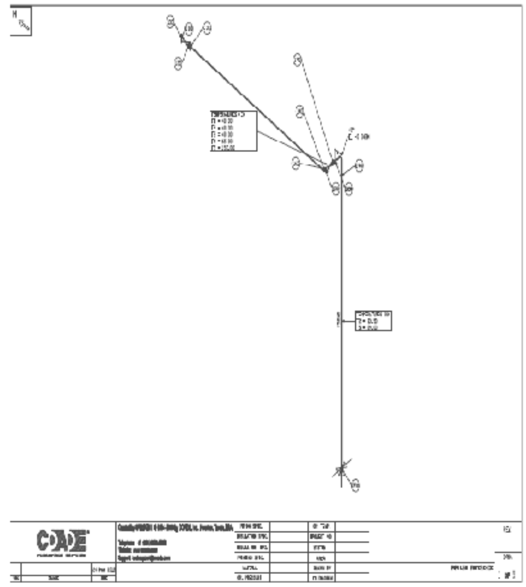

Fig. 4. Stress isometrics for pump discharge sheet 1 of 5.

Various parameters such as highest stresses (lb per square inch), code stress ratio (%), code stress, axial stress, bending stress, torsion stress, hoop stress, 3D max intensity, etc. are considered.After this, a restraint summary report showing loads on restraints is carried out.
CASE 1 (HYD) WW+HP
CASE 2 (OPE) W+T1+P1
CASE 3 (OPE) W+T2+P1
CASE 4 (OPE) W+T3+P1
CASE 5 (OPE) W+T4+P1
CASE 6 (OPE) W+T5+P2
CASE 7 (SUS) W+P1
CASE 8 (SUS) W+P2
A final displacement report is taken out for nodal movements for discharge case on CASE 2 (OPE) W+T1+P1.

IV. RESULTS AND DISCUSSION

The modeling framework has responded successfully to the various crucial tests & analysis. The CFRP pipe has passed all the critical tests such as stress/strain & displacement tests. All the values are under permissible limits. Loads on pump suction & discharge nozzles are as per code API- 610 & loads on tank nozzle are as per code API- 650. The maximum vertical deflection was taken out to be 15mm which was safely passed by CFRP pipes made up of nominal pipe size of 6 & 8mm. The stresses at steam out, sustained & expansion case are within allowable limits. CAESAR II has successfully performed the tests & has shown the allowable values under maximum values as per B31.3. The code stress compliance for both suction & discharge cases are shown in the respective tables.

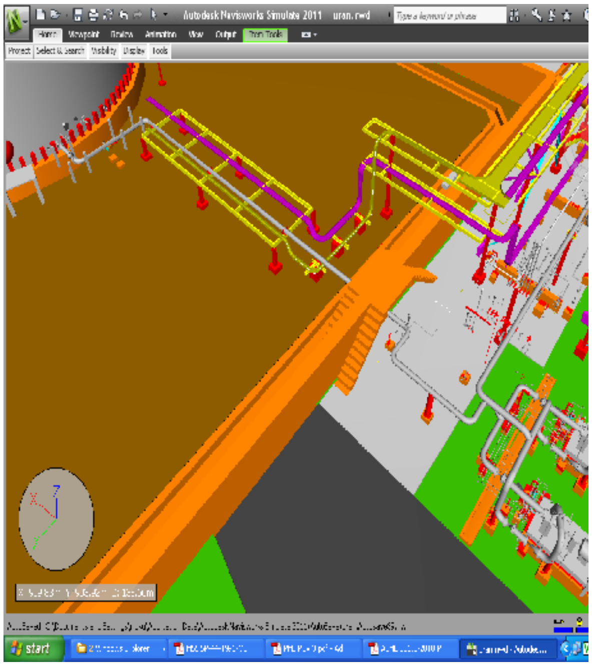

Fig. 5. Snapshot of the hypothetical oil refinery plant.

CODE COMPLIANCE: SUCTION

- CASE 12 (SUS) W+P1
- Piping Code: Multiple Codes
- BS 7159= BS 7159
  B31.3= B31.3 -2006
- *** CODE COMPLIANCE EVALUATION PASSED ***
- Highest Stresses: (lb./sq.in.)
- Code Stress Ratio (%) is 22.9 at Node 400
  LOADCASE: 12 (SUS) W+P1
- Code Stress: 4574.0 Allowable: 20000.0
- Axial Stress: 391.9 @Node 30
  LOADCASE: 12 (SUS) W+P1
- Bending Stress: 4201.1 @Node 400
  LOADCASE: 12 (SUS) W+P1
- Torsion Stress: 248.2 @Node 350
  LOADCASE: 12 (SUS) W+P1
- Hoop Stress: 2165.9 @Node 40
  LOADCASE: 12 (SUS) W+P1
- 3D Max Intensity: 4600.9 @Node 400
  LOADCASE: 12 (SUS) W+P1

CODE COMPLIANCE: SUCTION (TABLE)

Load Case	From Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	To Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	Piping Code
12 (SUS)	400	4574.0	20000.0	405	4560.0	20000.0	BS 7159

CODE COMPLIANCE: DISCHARGE

- CASE 7 (SUS) W+P1
- Piping Code: Multiple Codes
- B31.3 = B31.3 -2006
- BS 7159 = BS 7159
- *** CODE COMPLIANCE EVALUATION PASSED ***
- Highest Stresses: (lb./sq.in.)
- Code Stress Ratio (%) is 19.8 at Node 569
  LOADCASE: 7 (SUS) W+P1
- Code Stress: 3950.8 Allowable: 20000.0
- Axial Stress:1343.7 @Node 270
  LOADCASE: 7 (SUS) W+P1
- Bending Stress:1268.1 @Node 550
  LOADCASE: 7 (SUS) W+P1
- Torsion Stress: 122.5 @Node 200
  LOADCASE: 7 (SUS) W+P1
- Hoop Stress: 3950.6 @Node 569
  LOADCASE: 7 (SUS) W+P1
- 3D Max Intensity: 2929.2 @Node 210
  LOADCASE: 7 (SUS) W+P1

CODE STRESS COMPLIANCE: DISCHARGE

Load Case	From Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	To Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	Piping Code
7 (SUS)	569	3950.8	20000.0	570	3882.5	20000.0	BS 7159

V. CONCLUSION

Following are the conclusions made on the basis of testing and analysis of the hypothetical oil refinery plant (system):

- Stresses at sustained, expansion & steam out case are within allowable limits.
- Loads on Pump Suction & Discharge nozzles are as per code API- 610.
- Loads on Tank nozzle are as per code API-650.
- Vertical deflection due to sustained loads is within allowable.

New Product Development develops manufacturing plans and at the same time develops a new product design. Test proposed designs are made to see if they can be manufactured cost-effectively. Designing of new products with an eye to minimize the number of components is done under this. It is capable of supporting a number of engineering steps in product development. Efficient and innovative problem solving can be assisted by moderately coupled CAD, and FE software.

Simulations are carried out successfully and thus give significant contributions to the innovative climate and the productivity of project in product development. In an oil refinery plant, the proper labeling of pipes, valves, flanges and instrumentation in production and refining industry is critical. The use of simulation driven design for NPD has been carried out successfully by using a step by step approach of NPD for design and development. The steps under which the system is made and analyzed are: Research, Analyze, and Create, Select and Deliver.

The need of the product (taken as CFRP pipe in an oil refinery plant for carrying a fluid called Naphtha) has been identified and other alternatives are evaluated as well. A real-time model has been created and pilot runs are made after checking the accuracy, stability and efficiency of the product. The results of the create stage has been evaluated in the light of the situation analysis and strategic objectives. The final product with necessary changes has been delivered for the commercialization purpose.

VI. FUTURE SCOPE

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

Further, the need of CFRP for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures. CFRPs are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity.

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