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Stress Analysis For GRP Piping Systems - Literature Review

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ABSTRACT: *This review article focuses on the Glass Reinforced Polymer (GRP) pipes. The definition , benefits and detail procedure for Stress Analysis of GRP piping using CAESAR-II program which is based on code ISO14692 is described in detail. GRP pipe is a favourable alternative for concrete, coated-steel and other plastic pipes due to its several features which are elaborated in this article. With increasing knowledge of failure mechanisms, improved damage predictability and pipe quality, GRP piping is now a days considered more in the field of high pressure fluid transmission where pressure is in excess of several megapascals.*

KEY WORDS: *FRP piping, GRE piping, CAESAR II, Stress analysis*

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I. INTRODUCTION

A Glass Reinforced Plastic (GRP) Fiber is light in weight, very strong and a robust material. Although the strength is comparatively lower than carbon fiber and is less stiff, the material is typically far less brittle and the raw materials are cheaper. When compared to metals, the bulk strength and weight properties are also very favorable and it can be easily formed using molding processes.[1] In this world of rapidly developing economy, where the prominence of Nuclear power plants and its transportation is held in the highest regard, alternate methods of transporting large quantities of liquids (as in hot water) to the conventional options like metal pipes are studied. After a considerable amount of engineering considerations, which compared the advantages and disadvantages of various pipes, a GRP pipe is chosen as the best option because it provides lower thermal conductivity, which is an important factor in the transportation of hotter liquids. It also offers higher strength-to-weight ratio to metal pipes. GRP generally has resistance to corrosion, which gives it a longer lifetime than the metal pipes. GRP products being proprietary, the choice of component sizes, fittings and material types are limited depending on the supplier. The mechanical properties and design parameters varies from vendor to vendor. [2]

II. DEFINITION OF GRP PIPE

Glass Reinforced Pipes (GRP) are made from glass fiber reinforcements that are embedded in cured thermosetting resin. GRP Pipes are made of centrifugally cast glass fiber reinforced plastics (GRP) consisting of a combination of thermosetting plastics like for example unsaturated polyester or vinyl ester resins, chopped glass fibers and reinforcing agents. [3]

III. BENEFITS OF GRP PIPING

- Light weight- weight of GRP is only ¼th the weight of ductile iron pipe and is around 1/10th the weight of concrete pipe
- Corrosion resistance- GRP pipes are known for their long, effective service life, and they do not require any type of protection like cathode protection, and the hydraulic characteristics essentially remain unchanged over time.
- Extremely smooth bore-low friction loss means less pumping energy is needed, plus less slime build up can help in lowering the cleaning cost.
- Low maintenance cost-GRP pipes are easy to maintain because it does not rust, it is easily cleaned, and require minimal or no protection from environment.
- Long section of pipes-the standard length of pipe could reach up to 12 m, where fewer joints are needed which reduces the installation time and cost.

- Dimensional stability-GRP pipes can maintain the critical tolerance required for the most demanding structural and piping application.
- Material properties- GRP pipes meet the most stringent requirements as far as chemical resistance and mechanical strength.[4]

IV. GRP PIPE STRUCTURE

GRP pipes are made from many layers , the main layers are: (as shown in Figureure 1)

1) Inner layer - The inner layer shall be a thermosetting resin rich layer forming the interior layer of the pipe to give high corrosion resistance. The thickness of this layer shall be determined by the pipe manufacturer but shall not be less than 1 mm.
2) Barrier layer- The barrier layer shall have resin with or without reinforcement and with or without aggregate.
3) Structure layer- The structural layer shall consist of glass reinforcement and a thermosetting resin, with or without aggregates. The composition of structural layer depends on pipe pressure and stiffness class. Pipe mechanical strength is mainly achieved by the structural layer.
4) Outer layer – The outer layer is also rich with resin content and provides environmental protection to the pipe thickness**.**[5]

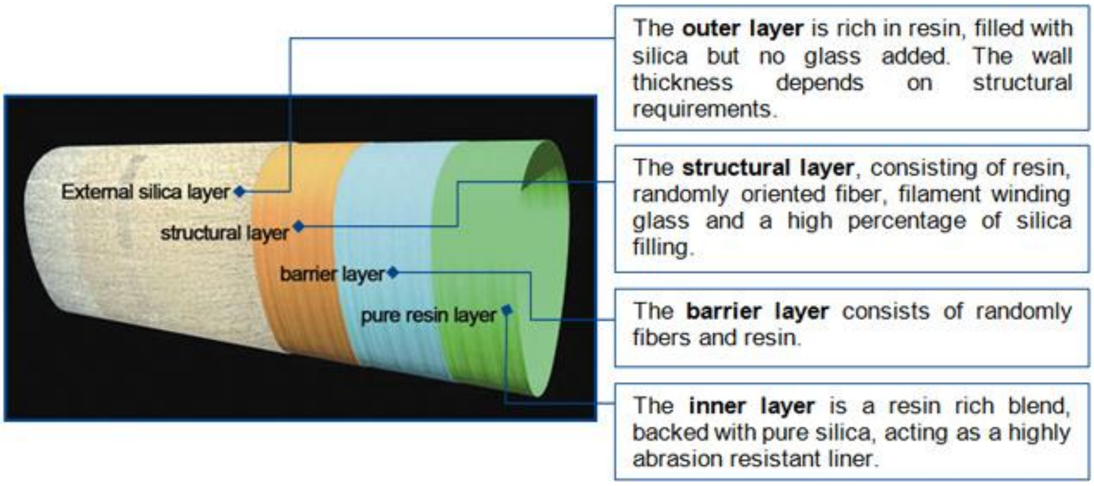

Figure 1: GRP Piping structure

V. GRP/FRP LAMINATE TYPE

The default laminate type (as defined in BS7159 code) of the fiber glass reinforced plastic Pipe used should be entered. The valid types are:

a) Chopped strand mat (CSM) & woven roving (WR) construction with internal & external surface tissue reinforced layer.

b) Chopped Strand Mat (CSM) & multi filament roving construction with internal & external surface tissue reinforced layer.

c) All chopped strand mat (CSM) construction with internal & external surface tissue reinforced layer. [6]

VI. STRESS ANALYSISI OF GRP / GRE / FRP PIPING SYSTEM USING CAESAR II

Stress analysis of GRP piping system is governed by ISO 14692 part 3. Several parameters (Figure. 2) for stress analysis have to be taken from vendor. The GRP material being orthotropic the stress values in axial as well as hoop direction need to be considered during analysis. [7][8] Before you open the input spreadsheet of Caesar II, communicate with the vendor through mail and collect the following parameters as listed in Figure.2.[9][10]

NOTE-The values shown in the above Figure are for example only. Actual values will differ from vendor to vendor. The above parameters are shown for a 6” pipe.

Parameters Required for GRP/GRE Piping Stress Analysis	
Pipe Diameter	**Parameter Values**
Pipe Outside Diamater, OD	165.7 mm
Pipe Structural Wall Thickness, tr	12.5 mm
Elbow Data	
Elbow structural wall thickness, ta	38.1 mm
GRE Mechanical Properties	
Elasticity modulus, Ea	17030 MPa
Elasticity modulus, Eh	28131 MPa
Shear modulus, G	11000 MPa
Poisson ratio, vhoop/axial	0.59
Poisson ratio, vaxial/hoop	0.36
Ea/Eh * Vh/a	0.36
Thermal expansion coefficient, α	15.7X10^(-6) mm/mm/C
Long Term Axial strength at 2:1 stress ratio, σal(2:1)	54.9 MPa
Long Term Axial strength at 0:1 stress ratio, σal(0:1)	39.3 MPa
Long Term Hoop strength at 2:1 stress ratio, σhl(2:1)	109.8 MPa
Qualified Stress for Joints, σ qs	109.8 MPa
Bi - Axial stress ratio for Joints [r]	1
Qualified Stress for Bends,σ qs	109.8 MPa
Bi - Axial stress ratio for Bends [r]	1
Qualified Stress for Tees, σ qs	109.8 MPa
Hoop modulus to the Axial Modulus Ratio, Eh/Ea	1.652
Thermal factor, K	0.85
Design Factors for GRE System	
System Design Factor, f2	0.67 (SUS), 0.83 (OPE), 0.89 (HYD)
System Design Factor, f3	1 (for U/G Pipe)
Partial Factor for Temperature, A1	1 (for Design temperature 75 deg. C)
Partial Factor for Chemical resistance, A2	1
Partial Factor for cyclic service, A3	1 (Static Design)

Figure 2: GRP pipe parameters

6.1 Inputs Required for Analysis:

For performing the stress analysis of a GRP piping system following inputs are required:

- GRP pipe parameters as shown in Figure. 2.
- Pipe routing plan in form of isometrics or piping GA.
- Analysis parameters like design temperature, operating temperature, design pressure, fluid density, hydro test pressure, pipe diameter and thickness etc.

6.2 Modeling in Caesar II:

Once all inputs as mentioned above are ready with you open the Caesar II spreadsheet. By default Caesar will show B 31.3 as governing code. Now refer to Figure. 3 and change the parameters as mentioned below:

1) Change the default code to ISO 14692.
2) Change the material to FRP (Caesar Database Material Number 20) as shown in Figure. 3. It will fill few parameters from Caesar database. Update those parameters from vendor information.
3) Enter pipe OD and thickness from vendor information.
4) Keep corrosion allowance as 0.
5) Input T1, T2, P1, HP and fluid density from line list.
6) Update pipe density from vendor information sheet, if vendor does not provide density of pipe then you can keep this value unchanged.
7) On the right side below the code, enter the failure envelop data received from vendor.
8) Enter thermal factor=0.85 if pipe is carrying liquid, enter 0.8 if the pipe carries gas.

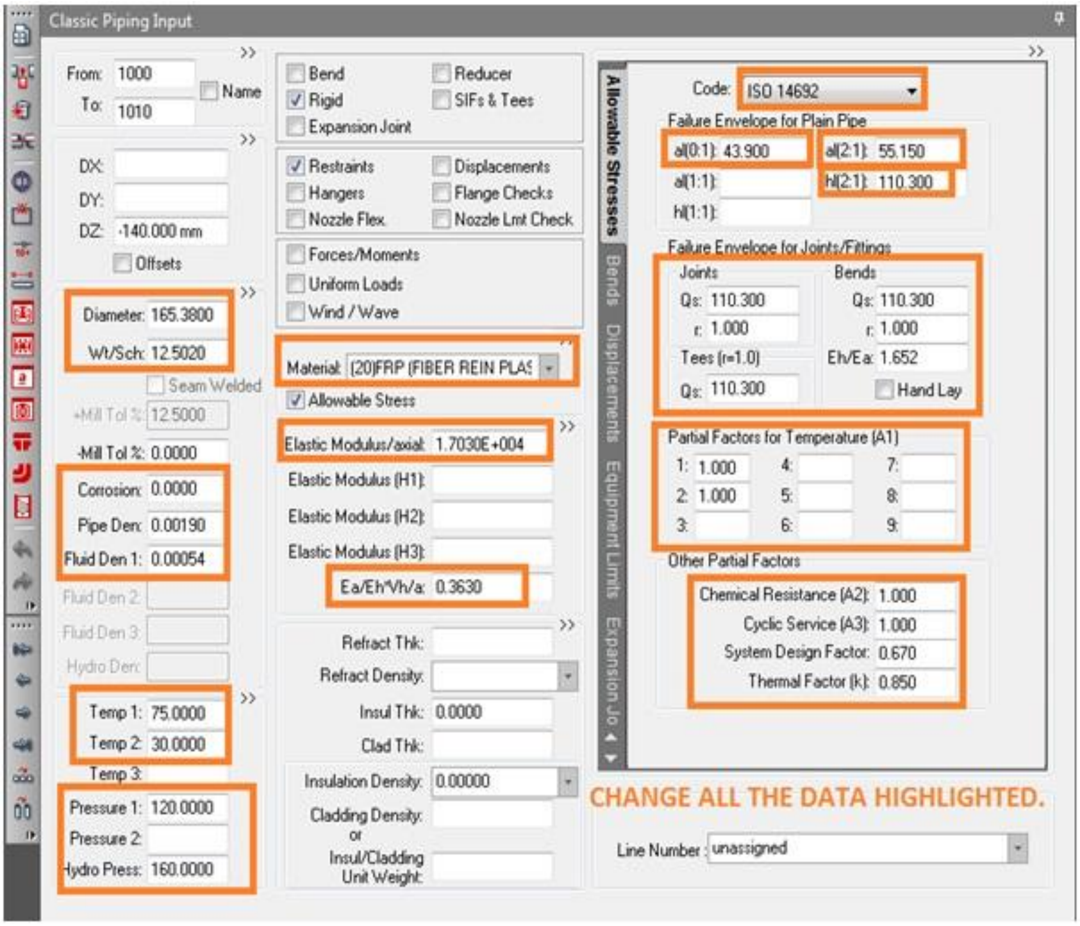

Figure 3: Modeling in Caesar II

9) After you have mentioned all the highlighted fields proceed modelling by providing dimensions from the isometric/piping GA drawing. Now add the supports at proper location from isometric drawing.
10) Now click on environment button and after page opens ,click on special execution parameter. It will open the window as mentioned in Figure 4.

Now Refer Figureure. 4 and change the highlighted parts from available data.

- Enter the GRP/FRP co-efficient of thermal expansion received from vendor.
- Calculate the ratio of Shear Modulus and Axial modulus and input in the location.
- In FRP laminate keep the default value if data is not available.
- After the above changes click on ok button.
- While modeling remember to change the OD and thickness of elbows/bends.

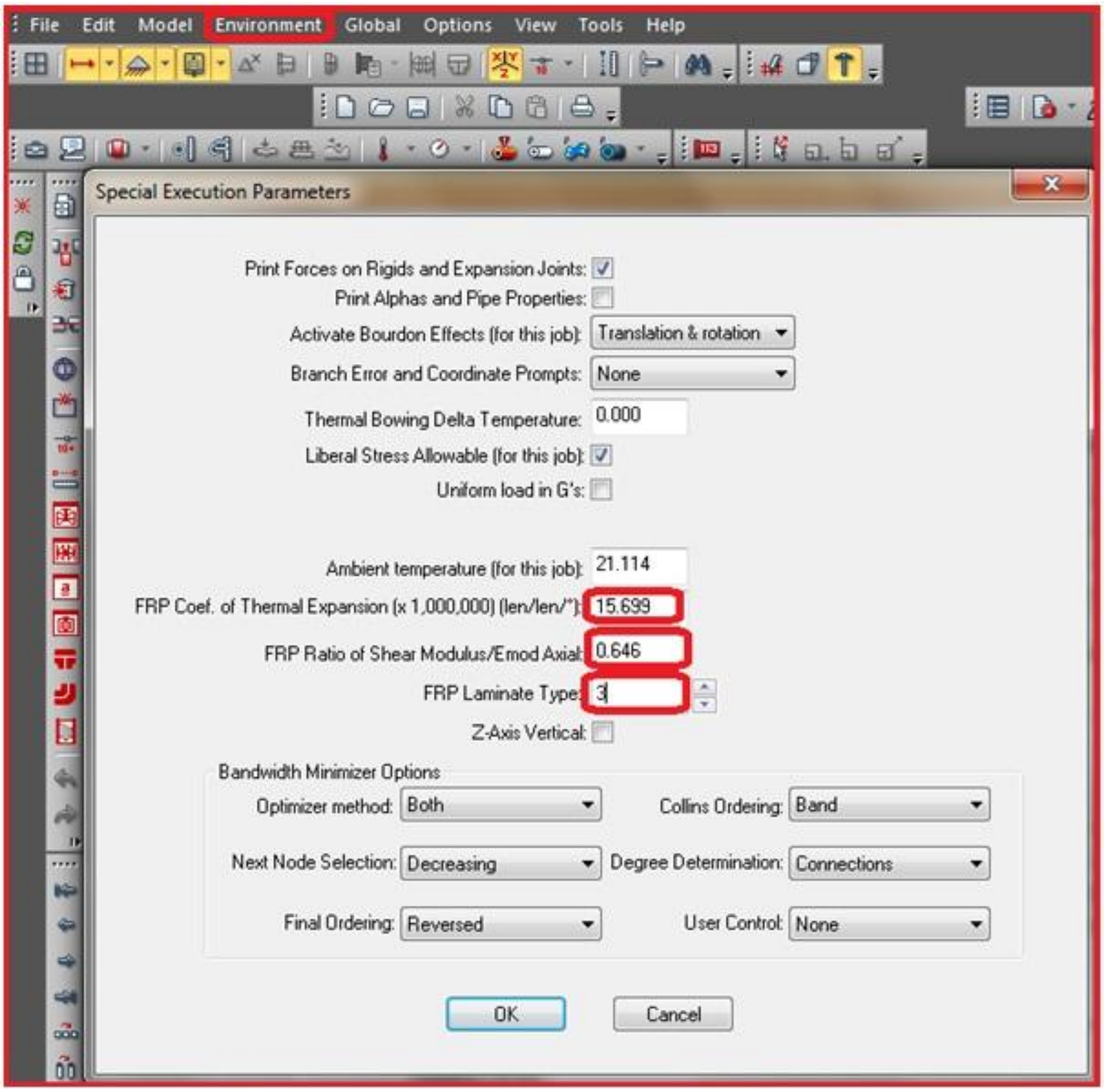

Figure 4: Special Execution Parameters

6.3 Modeling of Bend and Tee Connections:

- Modeling of bends is a bit different as compared to CS piping. Normally bend thicknesses are higher than the corresponding piping thickness. Additionally you have to specify the parameter, (EpTp) / (EbTb), which is located at the Bend auxiliary dialogue box as shown in Figure. 5. This value affects the calculation of the flexibility factor for bends.
- When you click on SIF and Tee box in Caesar II spreadsheet, you will find that only three options(Tee, Joint and Qualified Tee) are available for you as shown in Figure. 5. Each type has its own code equation for SIF calculation. Use the proper connection judiciously. It is always better to use SIF as 2.3 for both in-plane and out-plane SIF to adopt maximum conservative approach.[11]
  NOTE:- In terms of laminate types as described in BS 7159, only type 3 filament-wound laminates are considered.

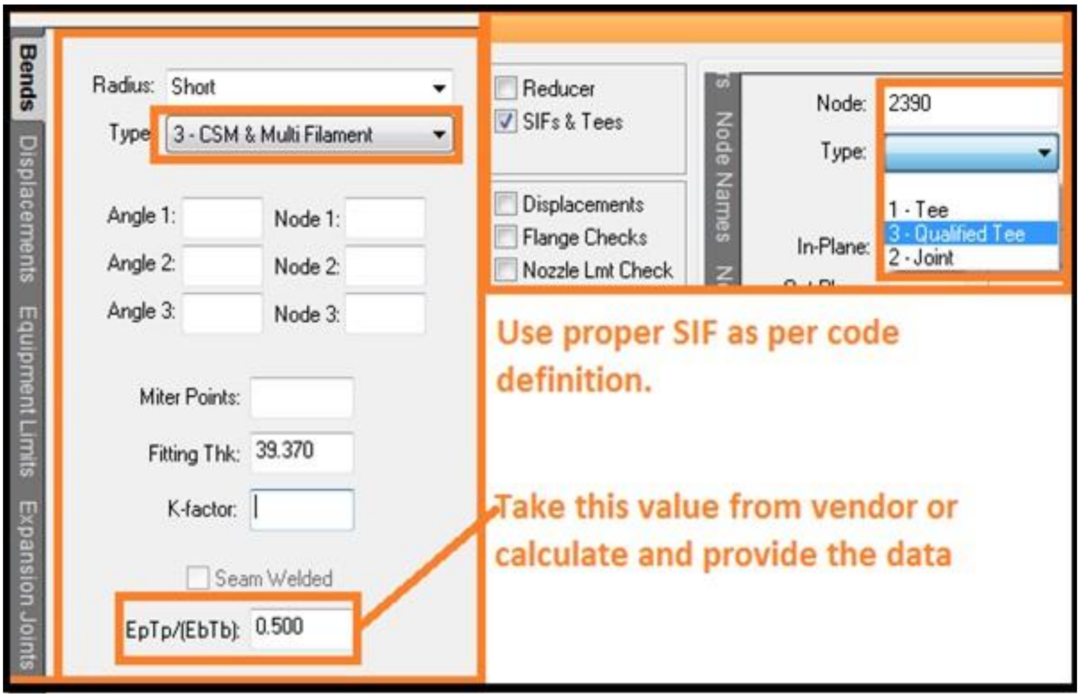

Figure 5: Modeling of Bend and Tee Connections

6.4 Load Cases for Analysis:

ISO 14692 informs to prepare 3 load cases: Sustained, Sustained with thermal and Hydro test. So accordingly the following load cases are sufficient to analyse GRP piping system

1. WW+H…………………...HYDRO
2. W+T1+P1………………..OPERATING - DESIGN TEMPERATURE
3. W+T2+P1………………..OPERATING - OPERATING TEMPERATURE
4. W+P1..…………………...SUSTAINED

The expansion load cases are not required to create as no allowable stress is available for them as per the code. While preparing the above load cases you have to specify the occasional load factors for each load case in load case options menu as shown in Figure.6 . ISO 14692 considers hydro test case as an occasional case. In higher versions of Caesar II software (Caesar II-2016 and Caesar II-2017) these load factors are taken care by default. So you need not enter the values. The option of these value entries will be available only if you define the stress type as occasional for those software versions.

The default values of occasional load factors are 1.33 for occasional case, 1.24 for operating case and 1.0 for sustained case. This occasional load factors are multiplied with system design factor (normally 0.67) to calculate the part factor for loading f2.

For aboveground GRP piping the above load cases are sufficient. But if the Line is laid underground then two different Caesar II files are required. One file for sustained and operating stress check and the other file for hydro testing stress check as the buried depth during hydro testing is different from the original operation. Also buried depth may vary in many places. So Caesar II modeling should be done meticulously to take care of exact effects.[12]

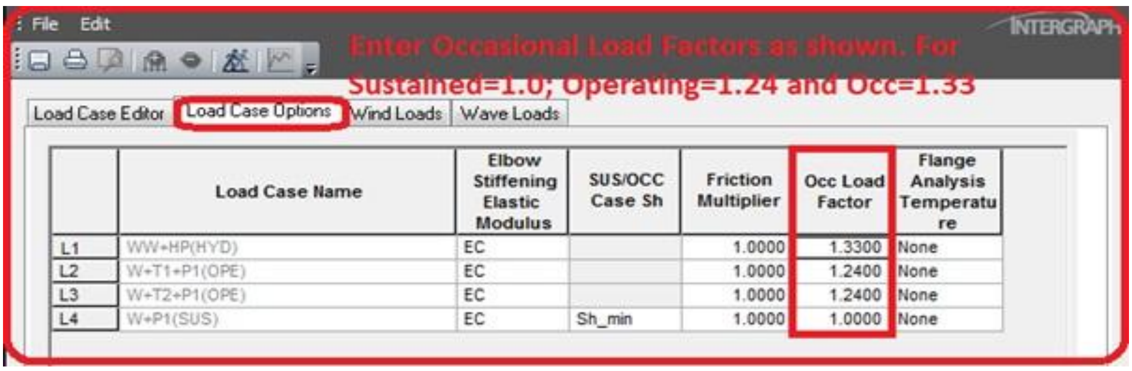

Figure 6: Specifying Occasional Load factors in Caesar II for GRP/FRP piping system

VII. SUPPORTING ASPECTS

- Standard CS support may not match GRP as Outer Diameter of pipe may be different.
- Use of Saddles & Elastomeric pads may allow the use of standard support.
- Support design should be as per vendor catalogue.
- Heavy in-line items like valves and strainers should be independently supported.
- Parasite supports (pipe to pipe) are not allowed.
- Supports on fittings should be avoided.
- Excessive clamping forces can cause crushing of the pipe.
- GRP spans are much less than the CS spans. In absence of vendor data for pipe span ,ISO 14692 can be used.
- Piping should be supported for shock loadings.
- Special care to be taken in freezing environment.[13]

VIII. CONCLUSION

It can be concluded that we can analyse GRP piping systems in CAESAR II software as per code ISO 14692. Potential GRP vendors need to be identified early in design stage to determine possible limitations of availability of the components. So it is of utmost importance that before you proceed for stress analysis of such type of system you must finalize the GRP/FRP/GRE vendor. More research work needs to be done on basic support standard for GRP /FRP/GRE piping systems.

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