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AN EXTENSION TO "ALLOWABLE DESIGN FACTOR" METHOD FOR FREE SPAN CALCULATION OF SUB SEA PIPELINES

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ABSTRACT

Using the design factors is a traditional method in solid mechanics design. This method is still also the base of some design standards in the world [۱،۲].In this paper, a modification has been performed to traditional Von Misses stress check method for the calculation of sub sea pipeline free spanning.

The DNV OS F۱۰۱ which is a well known standard for sub sea pipelines has been used for calibration [۳]. A spread sheet type program for free span calculation has been developed for "Force Model" which facilitates the evaluation of the free span length based on the latest DNV proposed method as well as traditional Von Misses stress check. The method statement is the calculation of maximum allowable sub sea pipeline free span, by DNV proposed method and consequently evaluation of allowable stress to result the same free span length in Von Misses traditional method. The design factors which are the Stress Factors (SF) will be calculated by the ratio of existing equivalent Von Misses stress to yield strength of the pipeline material (**fy**).

ASSUMPTION

There are a lot of parameters to be considered in the free span calculation. For calibration purposes, as mentioned above, the following assumption has been set:

۱- Internal pressure is greater than external pressure; hence the equation ۵,۲۳, D۵۰۰ of section ۵ of DNV OS F۱۰۱ applies [۳].
۲- The pipeline is on the seabed.
۳- Water depth is ۴۵ m and wave height and period ۱۱.۷ m & ۱۱.۵ secs respectively. For wave characteristic calculation, the Airy Wave theory has been used.
٤- The water current of ۱,۳ m/s at surface and ۰,۴ m/s for sea bed have been considered. The power equation of (۱/۷) has been used for current profile calculation.
٥- The water temperature has been considered ۱۳ ^{o}C.
٦- Pipeline material selected is API ۵L X۵۲.
۷- The sub sea pipeline is assumed to be in operating condition.
۸- The sub sea pipeline considered is "restrained".
۹- The study has been performed for two safety classes: "high" and "normal" as defined in section ۲, C۴۰۰ of DNV OS F۱۰۱ [۳].

The table ۱ shows the specifications of the pipelines studied.

Nominal D	Diameter (mm)	Thickness (mm)	D/t	Design T °C	Design P (Mpa)	Concrete Coating (mm)	Product Density (kg/m۳)
۶”	۱۶۸,۳	۱۲,۷	۱۳,۲	۸۰،۴۰	۱۵	۴۰	۴۰۰
۸”	۲۱۹,۱	۱۲,۷	۱۷,۲	۸۰،۴۰	۱۵	۴۰	۴۰۰
۱۰”	۲۷۳,۱	۱۲,۷	۲۱,۵	۸۰،۴۰	۱۲	۵۰	۳۲۰
۱۲”	۳۲۳,۹	۱۲,۷	۲۵,۵	۸۰،۴۰	۱۰	۵۰	۲۸۰
۱۴”	۳۵۵,۶	۱۲,۷	۲۸	۸۰،۴۰	۱۰	۵۰	۲۸۰
۱۶”	۴۰۶,۴	۱۲,۷	۳۲	۸۰،۴۰	۹	۵۰	۲۵۰
۱۸”	۴۵۷,۲	۱۲,۷	۳۶	۸۰،۴۰	۸,۵	۵۰	۲۴۰
۲۰”	۵۰۸	۱۲,۷	۴۰	۸۰،۴۰	۷,۰	۵۰	۲۲۵
۲۲”	۵۵۸,۸	۱۲,۷	۴۴	۸۰،۴۰	۶,۵	۶۰	۲۰۰
۲۴”	۶۰۹,۶	۱۲,۷	۴۸	۸۰،۴۰	۶,۵	۶۰	۱۹۰
۲۶”	۶۶۰,۴	۱۲,۷	۵۲	۸۰،۴۰	۶,۰	۶۰	۱۸۰
۲۸”	۷۱۱,۲	۱۲,۷	۵۶	۸۰،۴۰	۵,۵	۶۰	۱۶۰
۳۰”	۷۶۲	۱۲,۷	۶۰	۸۰،۴۰	۵,۰	۷۰	۱۵۰

TABLE ۱, ASSUMED PIPELINE PROPERTIES

METHOD STATEMENT

The method statement has been completely defined in the Figure ۱ below. As it is shown in the below chart it divided to the ۳ following steps.

Step ۱, evaluating the free span length “L” in accordance with DNV OS F۱۰۱ section ۵ and by using the following formula [۳].

$$\gamma_{SC}\gamma_m\left(\frac{S_d}{\alpha_C S_P}\right)+\gamma_{SC}\gamma_m\left(\frac{M_d}{\alpha_C M_P}\sqrt{۱-\left(\frac{\Delta p_d}{\alpha_C p_b(t_۲)}\right)^{۲}}\right)+\left(\frac{\Delta p_d}{\alpha_C p_b(t_۲)}\right)^{۲}\leq ۱$$

(۱)

Step ۲, stress calculation, the unsupported pipe section will be subjected to longitudinal bending stresses resulting from the submerged weight of the pipe as well as environmental loads in addition to the stresses caused by the design temperature and pressure. The corresponding stresses with above calculated L will be as follows [۵]:

$$\sigma_B=\frac{FDL^{۲}}{KI}$$

(۲)

s_B = Existing bending stresses
D =Outside diameter of the pipe
I= Moment of Inertia of the pipe
K= Constant for end fixity, ۱۶ for fix-fix, ۲۴ for pin-pin. A value of ۲۰ corresponding to fix-pin condition has been considered in this study.
F =Uniform Loading on pipe

$$F = \sqrt{W_{SUB}^{۲} + (F_D + F_I)^{۲}}$$

(۳)

W_{SUB}=Total submerged weight of the pipe
F_D=Environmental Drag force
F_I = Environmental Inertia force

$$\sigma_h = \frac{\gamma_p (p_{ld} - p_e)(D - t_{۲})}{۲t_{۲}}$$

(۴)

s_h=Hoop stress
g_p=Pressure load factor
$t_{۲}$= Pipeline corroded wall thickness
p_{ld}=pipeline design pressure
p_e=External pressure

$$S_F = -\Delta p_i A_i (۱ - ۲\nu) - A_S E \alpha \Delta T$$

(۵)

S_F = Effective functional axial force for restrained section
Dp_i = Internal pressure difference relative to external pressure
A_i = Cross sectional area relative to inside diameter
A_s = Cross sectional area of the pipe steel
DT = Operating Temperature difference with water Temperature
E = Modulus of Elasticity
a = Steel expansion temperature coefficients

$$\sigma_X = \frac{S_F}{A_S} + \sigma_B$$

(۶)

$$\sigma_e = \sqrt{\sigma_X^{۲} + \sigma_h^{۲} - \sigma_X \sigma_h}$$

(۷)

Step۳, evaluating the design factors (stress factors), Df (SF)

$$Df(SF) = \frac{\sigma_e}{f_y}$$

(۸)
f_y =Characteristic pipeline material properties with consideration of temperature de-rating as specified at DNV OS F۱۰۱ SECTION ۵, B۶۰۰ [۳].

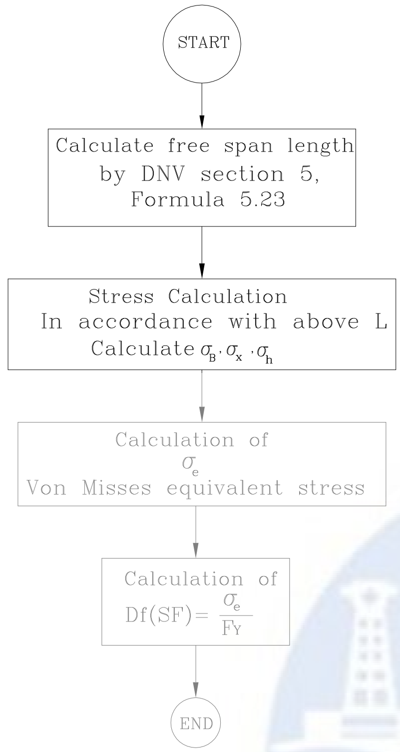

FIGURE-۱, METHOD STATEMENT FLOW CHART

The above mentioned stepwise procedure has been exercised for the pipelines in Table ۱.

RESULTS & CONCLUSIONS

The figure-۲ has shown the results of the analysis. Investigation of calculated stress design factors shows the following results:

۱- The stress design factors have not been limited to a figure as stated into traditional theory.

۲- The important parameters such as D/$t_{۲}$ (D=external diameter of the pipe & $t_{۲}$=pipeline corroded wall thickness) and design temperature (T) play crucial role.

۳- The variation of SF with D/$t_{۲}$ is almost linear.

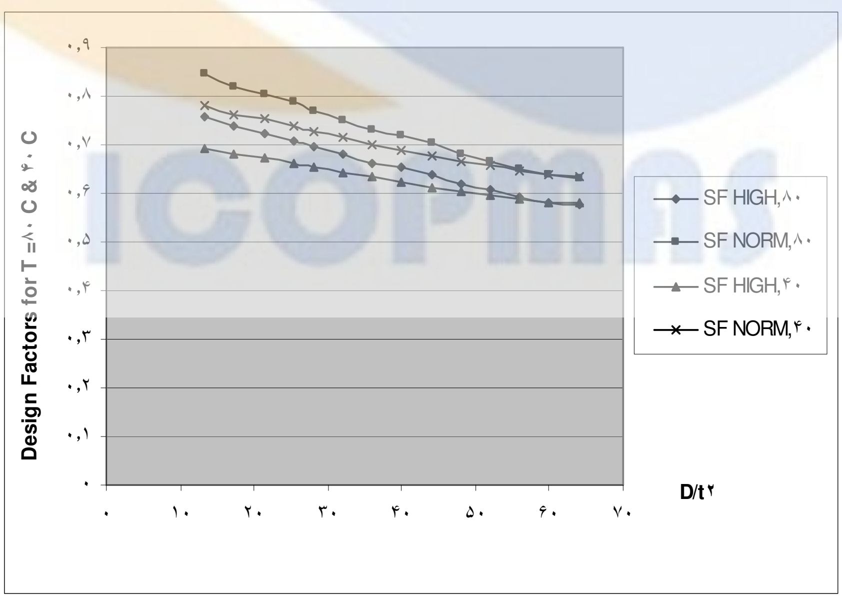

FIGURE-۲

As a result of this study the following equation for evaluation of the stress factors (SF) in accordance with ($D/t_۲$, T), is developed :

$$SF_N = ۰.۸۱ - ۰.۰۰۲۹\frac{D}{t_۲} + \left(۰.۰۸۱۹ - ۰.۰۰۱۳۸\frac{D}{t_۲}\right)\frac{(T-۴۰)}{۴۰} \quad (۹)$$

$$SF_H = ۰.۷۲ - ۰.۰۰۲۳۵\frac{D}{t_۲} + \left(۰.۰۷۹۴ - ۰.۰۰۱۳\frac{D}{t_۲}\right)\frac{(T-۴۰)}{۴۰} \quad (۱۰)$$

SF_N = Stress factor in Normal safety condition
SF_H = Stress factor in High safety condition
T = Design Temperature

The use of the above two equations, is recommended in the following condition:

- $۲۰ \le T \le ۸۵$ °C
- $\frac{D}{t_۲} \le ۴۵$

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