A platform in Indonesia that collapsed due to a ship collision [1]

ASSESSMENT OF PROBABILITY OF FAILURE OF STEEL JACKET STRUCTURES SUBJECT TO SHIP COLLISION IN OFFSHORE VIET NAM

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Summary

The paper presents a reliability approach to assess the impact of ship collision on the existing jacket platforms in the waters of Viet Nam. The approach adopts the limit state concept for boat impact energy and platform structural absorption energy capacity to assess the structural failures. Two boat impact energy spectra, representing the 50th and 95th percentiles of impact energy, are used to determine the probability of platform structural failure. In this paper, the platform structural absorption energy of one representative steel jacket type platform is determined using SACS "Collapse" module based on plasticity for structural members which will subsequently contribute to the loss of global structural stiffness.

The study provides an insight into the maximum boat impact energy for steel jacket type platforms which can be mitigated by other means such as regulation of structural design criteria and marine operations.

1. Introduction

The recent Bombay High disaster and the collision of a boat with a braced monopod platform located offshore Madura island in Indonesia have alerted Operators in Southeast Asia to the need for assessment of the marine operation safety of their offshore installation. The above kind of disaster has previously been experienced by Operators in the North Sea and the Gulf of Mexico as recorded and studied by HSE [12].

The study was based on the incident reports from 1975 to 2001 for passing and attendant vessels indicating that the frequency of incidents per year for fixed installations was 6.3% resulting in moderate or severe damage per year of 0.95% of total vessel collisions.

Efforts to minimise the installation vessel collision and damage rates were made by implementing more stringent marine operation regulations and structural means of providing higher structural absorption energy. In response to structural safety requirements, researchers have explored ways of enhancing the structural absorption energy emphasising structural nonlinear geometrical and material nonlinearity [3 - 9] including pipe dent mechanism, which eventually merged into Codes and Regulations [2, 10, 11].

2. Development of Vessel Motion Energy Model

Both Code and Guidance [2, 9] recommended the vessel impact energy “E_V” is expressed as the product of vessel motion energy in free field times a relative mass-velocity factor representing the installation flexibility and mass. The vessel impact energy “E_V” is determined by the following equation:

$$E_V = E_S + E_I = \left(\frac{1}{2}\left(M_s + M_{sa}\right)V_s^{\,2}\right)\left(\frac{\left(1-\frac{V_i}{V_s}\right)^2}{1+\frac{M_s+M_{sa}}{M_i+M_{ia}}}\right) \qquad (1)$$

Where E_S, E_I, M_S, M_{Sa}, M_I, M_{Ia}, V_S and V_I are ship energy absorption; installation (structural) absorption energy; ship loaded displacement mass; ship added mass based on stern collision; effective installation mass; installation added mass; ship free-field velocity and installation induced velocity, respectively.

The vessel motion energy representing the first term in brackets on the RHS of Eq.(1) is statistically conducted using data of available sixteen attendant vessels as shown in Table 1.

***Table 1.** Vessel Particular Data*

No	Vessel Name	Vessel Types	Overall Length (m)	Breadth (m)	Depth (m)	Draft (P100) (m)	DWT (P100) (Mtons)
1	AHTS-Bourbon Liberty 219	Anchor Handling Tug Supply	59.78	15.00	5.50	4.30	1460.00
2	AHTS-Seacor Valor	Anchor Handling Tug Supply	67.00	14.00	6.00	5.00	2198.00
3	Jaya Amandam	Anchor Handling Tug Supply	58.70	14.60	5.50	4.75	1350.00
4	Mary K	Anchor Handling Tug Supply	59.00	14.60	5.50	4.50	1275.00
5	Sapa	Anchor Handling Tug Supply	64.40	13.80	6.90	5.88	1950.00
6	Bourbon Liberty 118	Support Vessel	57.90	14.00	5.50	4.90	1509.00
7	Thanh Long	Anchor Handling Tug Supply	81.16	16.30	7.20	4.90	1382.00
8	Greatship Ahalya	Towing & Supply Vessel	63.00	15.00	6.10	5.20	1600.00
9	Binh Minh	Anchor Handling Tug Supply	61.00	14.95	5.80	4.80	1500.00
10	Visal 2	Towing & Supply Vessel	53.34	11.58	4.57	3.81	343.00
11	Visal Sai Gon	Towing & Supply Vessel	64.40	13.80	6.90	5.90	1875.00
12	FALCON 06	Multipurpose tug boat	34.00	9.93	4.60	3.70	268.20
13	Dau Khi 101	Utility Standby Vessel	50.06	11.62	3.50	2.62	606.75
14	Dau Khi 105	Utility Standby Vessel	39.00	9.50	3.21	1.70	479.16
15	Dau Khi 106	Utility Standby Vessel	50.03	11.58	4.26	2.16	678.00
16	Phu My 06	Support Vessel	50.60	11.50	3.96	3.40	467.00

This minimum information is used to statistically develop a vessel motion energy model for the structural assessment of fixed steel jacket platforms against vessel collision in the Vietnamese waters. Some fundamental assumptions are set for 50th percentile data such as for loaded displacement based on 80% DWT and for economic vessel speed. These vessel loaded displacement values inherit a variation of 10% as the lightship weights are not available but the prediction is based on block coefficient for this type of supply vessel. Furthermore, the cruising and maximum vessel speeds are considered as the 80th and 100th percentiles, respectively, by which together with the P50 vessel speed, the vessel speed probability distribution model using three-parameter Weibull Distribution is generated as shown in Tables 2 and 3, where location parameter γ is not shown.

Table 2. *Weibull Distribution Parameters for Vessel Speeds*

No	Vessel Name	Vs (Knots) (P50)	Vs (Knots) (P80)	Vs (Knots) (P100)	Weibull Distribution			Vessel Types
					Beta (β)	Alpha (α)	Std (σ)	
1	AHTS-Bourbon Liberty 219	9.00	12.00	13.00	3.05	10.20	0.326	AHT Supply Vessel
2	AHTS-Seacor Valor	10.00	11.00	13.00	8.00	10.35	0.844	AHT Supply Vessel
3	Jaya Amandam	10.00	10.90	13.50	8.00	10.45	0.836	AHT Supply Vessel
4	Mary K	10.00	11.10	13.00	8.00	10.45	0.836	AHT Supply Vessel
5	Sapa	10.00	12.00	15.00	6.00	10.70	0.613	AHT Supply Vessel
6	Bourbon Liberty 118	10.50	11.50	12.50	9.00	10.90	0.903	Support Vessel
7	Thanh Long	9.00	10.00	13.00	7.00	9.35	0.814	AHT Supply Vessel
8	Greatship Ahalya	9.00	11.00	13.50	4.20	9.80	0.467	Towing Supply Vessel
9	Binh Minh	10.00	12.00	13.70	4.70	10.80	0.476	AHT Supply Vessel
10	Visal 2	9.50	10.65	12.00	7.40	9.95	0.811	Towing Supply Vessel
11	Visal Sai Gon	8.00	9.00	12.00	7.00	8.40	0.901	Towing Supply Vessel
12	FALCON 06	10.00	10.60	12.00	10.20	10.35	1.076	Multi-purpose tug boat
13	Dau Khi 101	6.50	7.65	9.50	5.50	6.94	0.848	Utility Standby Vessel
14	Dau Khi 105	6.50	7.65	9.50	5.50	6.94	0.848	Utility Standby Vessel
15	Dau Khi 106	7.50	9.50	12.50	3.70	8.30	0.482	Utility Standby Vessel
16	Phu My 06	9.50	10.65	13.00	7.40	9.95	0.811	Support Vessel

Table 3. *Weibull Distribution Parameters for Vessel Motion Energy*

No	Vessel Name	EV (MJ) (P50)	σEv	Alpha	Beta	Gama
1	AHTS-Bourbon Liberty 219	28.39	2.03	3.05	10.20	19.30
2	AHTS-Seacor Valor	41.52	7.09	8.00	10.35	31.63
3	Jaya Amandam	37.52	6.09	8.00	10.45	27.52
4	Mary K	35.75	5.80	8.00	10.45	25.76
5	Sapa	47.58	5.74	6.00	10.70	37.50
6	Bourbon Liberty 118	39.80	6.75	9.00	10.90	29.30
7	Thanh Long	50.03	8.50	7.00	9.35	41.16
8	Greatship Ahalya	36.74	3.70	4.20	9.80	25.78
9	Binh Minh	40.21	3.73	4.70	10.80	30.20
10	Visal 2	20.62	3.24	7.40	9.95	11.15
11	Visal Sai Gon	27.84	6.20	7.00	8.40	19.87
12	FALCON 06	11.90	2.41	10.20	10.35	1.91
13	Dau Khi 101	6.31	1.62	5.50	6.94	0.00
14	Dau Khi 105	2.35	0.67	5.50	6.94	0.00
15	Dau Khi 106	6.10	0.81	3.70	8.30	0.00
16	Phu My 06	16.91	2.73	7.40	9.95	7.44

Taking the upper-bound values of P50 vessel motion energy, the vessel motion energy model can be developed as shown in Fig.1.

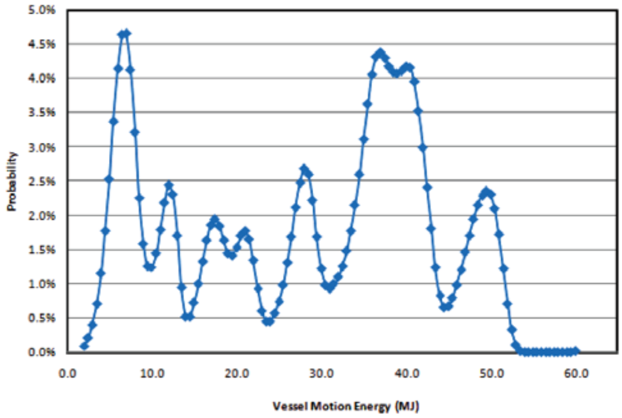

Fig.1. *Vessel Motion Energy Model based on P50*

3. Development of Vessel Impact Energy Model

In view of Eq.(1), it can be seen that the factor is specific depending on the installation mass and added mass as well as the installation velocity during collision. This installation velocity is related to platform structural stiffness and pipe dent stiffness at the hit point. Platform structural absorption energy model can be developed using a number of platform structural data for the specific location.

In reference to the same impact force acting at the jacket tubular legs or braces causing the tubular displacement and pipe dent, the following equation can be derived as:

$$\delta_D = \frac{\left(a\Delta^2 + b\Delta + c\right)\Delta t^3}{P^2}\left(\frac{21F_Y}{4}\right)^2 \tag{2}$$

$$\delta_D = \frac{\left(a\Delta^2 + b\Delta + c\right)\Delta t^4}{P^2 D}\left(\frac{150F_Y}{4}\right)^2 \tag{3}$$

Where: Δ, δ_D, P, D, t, F_y, a, b and c are joint displacement of hitting point; pipe denting; impact force; pipe diameter; pipe wall thickness; mean yield stress; pipe flexural stiffness parameters and stiffness constant, respectively. The flexural stiffness parameters and constant are determined using the stress analysis of platform structure due to impact energy applying at the hitting point.

Eq.(2) based on Amdahl's impact force for pipe dent [6] holds for D/t ratio of pipe less than 50, while Eq.(3) which is based on Ellinas and Walker work [6] for D/t ratio of pipe greater than 50.

When the ship absorption energy is assumed to be zero, and the installation flexural absorption energy is modelled as a polynomial function of power two, the vessel impact energy is equal to the installation absorption energy which is contributed by tubular flexural and pipe dent mechanism. The following expression for ship and installation absorption energy holds true for any deformations of ship and installation:

$$E_V = E_S + E_I = \frac{7F_y\left(\delta_D t\right)^{\frac{3}{2}}}{2} + \left(\frac{a\Delta^4}{4} + \frac{b\Delta^3}{3} + \frac{c\Delta^2}{2}\right) \tag{4}$$

$$E_V = E_S + E_I = \frac{25F_y\left(\delta_D\right)^{\frac{3}{2}} t^2}{D^{\frac{1}{2}}} + \left(\frac{a\Delta^4}{4} + \frac{b\Delta^3}{3} + \frac{c\Delta^2}{2}\right) \tag{5}$$

The installation velocity in Eq.(1) can be approximated from the dynamic response of installation (platform structure) at the hit point as shown below:

$$V_I \cong \omega_1\left(\Delta + \delta_D\right) \tag{6}$$

Where:

V_I: Velocity of platform (cm/s);

ω_1: Structure frequency at first mode from Eigenvalue analysis;

Δ: Impacted joint displacement at first mode (cm);

δ_D: Dent depth (cm).

By performing an iterative calculation using Eqs.(2 - 6), the impact force, the pipe dent, the joint displacement tubular leg or brace, the installation (structural) velocity and vessel impact energy can be determined.

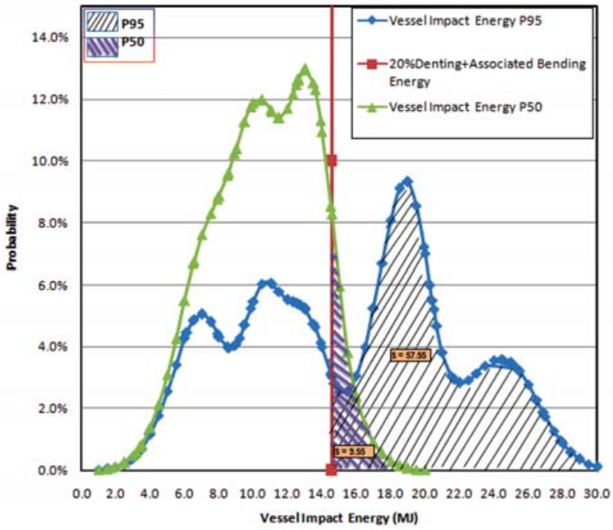

Fig.2. *Vessel Impact Energy Model*

With the same method based on probability density function (pdf) of vessel impact energy P95, the vessel impact energy model P95 can be found. Combine two Vessel Impact Energy Models (P50 & P95) with 20% denting plus associated bending energy, with the result expressed as in Fig.2.

Standard deviation of vessel impact energy σ_{EV} can be expressed as Eq.(7):

$$\sigma_{EV} = \sqrt{\left(\frac{\partial E_V}{\partial M}\sigma_M\right)^2 + \left(\frac{\partial E_V}{\partial V}\sigma_V\right)^2 + \left(\frac{\partial E_V}{\partial f}\sigma_f\right)^2} \qquad (7)$$

Where: σ_M, σ_V and σ_f are standard deviations of vessel loaded displacement; vessel velocity and relative mass-velocity factor, respectively

4. Structural Failure Criteria

The adopted structural criteria may vary from one company to another depending on the target risk level acceptable to the company. In this study, the local surrounding structural member failure is limited to plastic hinges and depth of pipe dents developed on the collided structural member, while the global structural inelastic response behaviour is taken into account based on plastic hinges on the surrounding collided structural member.

In reference to API RP 2A LRFD [13], where the nominal bending stress is replaced by the mean yield strength F_y, the following failure criteria for structural members under combination of tension with bending moment in Eq.(8) and of compression and bending moment in Eqs.(9 - 10) can be expressed as below:

$$\Gamma = -\cos\left[\frac{\pi}{2}\left(\frac{f_t}{F_y}\right)\right] + \left[\left(\frac{f_{by}}{F_y}\right)^2 + \left(\frac{f_{bz}}{F_y}\right)^2\right]^{1/2} \le 0 \qquad (8)$$

$$\Gamma = -\cos\left[\frac{\pi}{2}\left(\frac{f_c}{F_{xc}}\right)\right] + \left[\left(\frac{f_{by}}{F_y}\right)^2 + \left(\frac{f_{bz}}{F_y}\right)^2\right]^{1/2} \le 0 \qquad (9)$$

$$\Gamma = \frac{f_c}{F_{xc}} + \left[\left(\frac{C_{my} f_{by} / F_y}{\left(1 - \frac{f_c}{F'_{ey}}\right)}\right)^2 + \left(\frac{C_{mz} f_{bz} / F_y}{\left(1 - \frac{f_c}{F'_{ey}}\right)}\right)^2\right]^{\frac{1}{2}} - 1 \le 0 \qquad (10)$$

Where the notation in Eqs.(8 - 10) can be referred to API RP 2A LRFD, 1993.

If the ratio of compressive stress to member buckling stress is over 0.15, the Eq.(10) can be used instead of Eq.(9).

The pipe dent criteria is based on maximum dent depth to diameter ratio or maximum allowable dent depth such as annulus width of ungrouted jacket leg in order to satisfy the applicability of the dent pipe formulations. DNV [11] stipulated 20% of diameter as the failure criteria for pipe denting, by which the pipe dent absorption energy can be expressed in Eqs.(11 - 12):

$$\left(E_D\right)_{\max} = 2.236 F_y D t^2 \qquad (11)$$

$$\left(E_D\right)_{\max} = 0.313 F_y \left(Dt\right)^{1.5} \qquad (12)$$

Where:

$(E_D)_{max}$: Maximum dent energy;

D: Pipe diameter;

t: Pipe thickness.

5. Structural Absorption Energy

To determine the structural bending energy of a steel jacket platform, an integrated pile-jacket and topside structural model is developed using SACS software package as shown in Fig.3. To do so, a non-linear progressive analysis is adopted and performed by SACS - Collapse module, with failure criteria of structural members limited to the development of plastic hinges [14].

The computed structural bending (flexural) energy using non-linear progressive analysis takes into account the global flexibility of integrated jacket-topside with pile and local structural absorption energy of both collided and surrounding members. The pipe denting energy is computed based on Amdahl formula [6] for diameter to

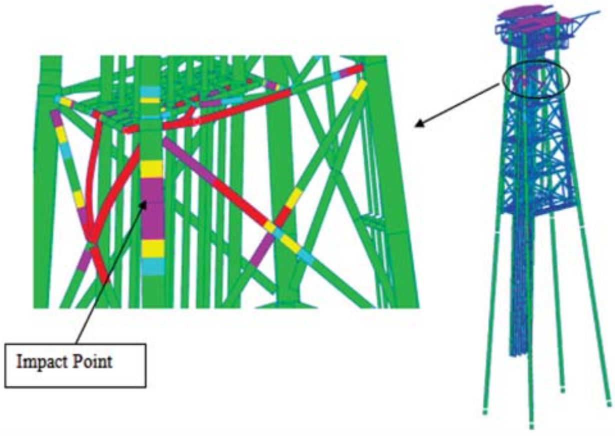

Fig.3. *Step 31-Plastic Hinges members occur*

thickness ratio less than 50, otherwise Ellinas & Walker formula is applied. The result is shown in Fig.4.

Fig.4 shows a specific structural bending and pipe denting energy for a particular steel jacket type platform in the Vietnamese waters. No detailed FEM is conducted to investigate the local pipe denting deformation, except by implementing the dent depth only Eqs.(2 - 3). The interaction between the structural stiffness of the global structure and pipe dent is represented using a series system of interaction by maintaining the same impact force at the structural member and pipe dent point.

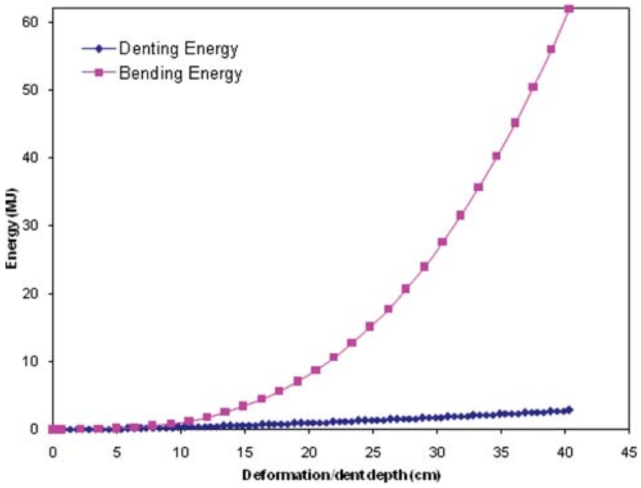

Fig.4. *Structural bending and pipe denting absorption energy*

6. Probability of Structural Failure

The probability of failure P_f for the damage of a collided tubular brace or jacket leg can be determined using the limit state function (Z) which is described by the fault tree diagram below:

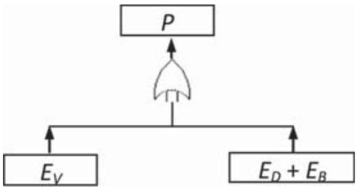

Fig.5. *Boolean algorithms to assess the probability of structural member damage*

The above representation can be expressed with the equation below:

$$Z = E_I - E_V = (E_B + E_D) - E_V \quad (13)$$

$$\sigma_Z = \sqrt{(\sigma_B^2 + \sigma_D^2) + \sigma_V^2} \quad (14)$$

Where: E_B and E_D are structural bending absorption energy and pipe denting energy respectively, as shown in Fig.4.

From Eq.(13), the probability of failure P_f is defined when Z < 0.

Based on the above theory the probability of structural failure P_f caused by ship impact is determined as the area of cross section shown in Fig.6.

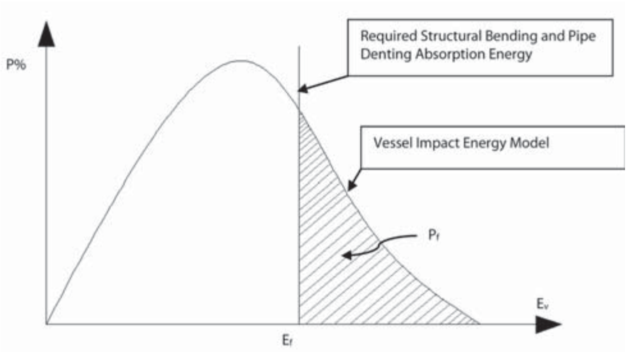

Fig.6. *Probability of structural failure P_f caused by ship impact*

Where:

E_f Required structural bending and pipe denting absorption energy, is presented as Fig.2, section 3 of this account.

7. Conclusions

With minimum vessel particulars and operational data, the study can present only preliminary findings on boat kinetic (motion) energy and probability of failure of a collided platform structure. Nevertheless, the presented approach can still be used as a guideline for the structural assessment of a boat collision against a jacket leg and braces. The findings can be refined by updating the study using more data concerning vessel particulars and platform structures.

The study shows that based on failure criteria of 20% dent depth ratio and local plastic failure of collided member, the probabilities of failure of the collided jacket leg are approximately 10% for mean vessel speed and 57% for P95 vessel speed, respectively. These findings indicated more than 50% of jacket legs will fail if collided by P95 vessel speed and about 10% for collision due to mean vessel speed.

Furthermore, the findings also provide insight for Operators in the Vietnamese waters on boat impact energy criteria for designing jacket legs, braces and boat landings due to accidental loads, besides implementing marine operation regulations. Further studies on failure risk, economical aspects and mitigation means are therefore recommended to meet target acceptance criteria based on acceptable risk levels.

8. Appendices

8.1. Interpretation of symbols

(1), (2) - P50 and P95

$$P50 = P(0 < x < x_{50}) = \int_0^{x_{50}} f(x)dx$$

$$P95 = P(0 < x < x_{95}) = \int_0^{x_{95}} f(x)dx$$

Random Variable x - Velocity of Vessel

Cumulative Distribution Function $F(x) = \int_0^{\infty} f(x)dx$

Probability Density Function f(x) of a Weilbull distribution.

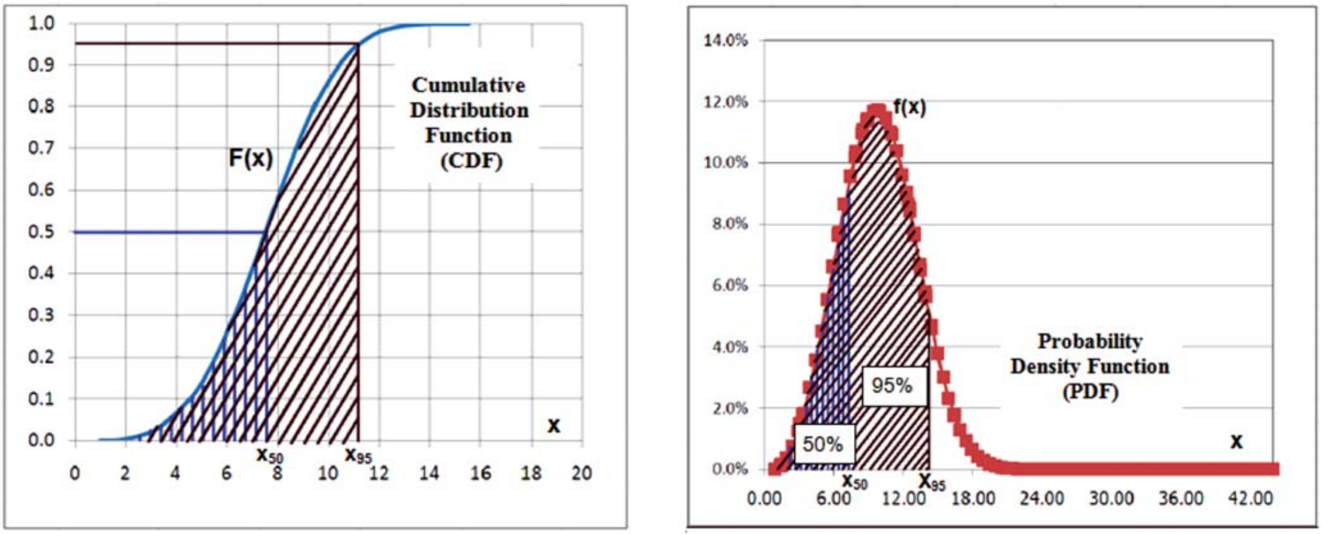

Fig.7. *Cumulative distribution and probability density function*

8.2. Summary of results extracted from SACS Version 5.3

Table 4. *Special Event History Report (summary)*

Load Step	Load Cond	Load Factor	Joint/member/plate	Length (m)	Subseg	Plasticity	Event
19	500	36	BI01 L103	0.000	1	0.167	Plastic
19	500	36	L203 BI01	8.100	9	0.083	Plastic
20	500	38	152 L103	3.193	9	0.083	Plastic
21	500	40	180 130	0.000	1	0.083	Plastic
21	500	40	BI01 L103	0.545	2	0.083	Plastic
21	500	40	L203 BI01	6.954	8	0.083	Plastic
21	500	40	LI01 P103	0.000	1	0.167	Plastic
21	500	40	P303 LI01	12.047	8	0.167	Plastic
22	500	42	152 L103	2.761	8	0.083	Plastic
23	500	44	202 L103	9.163	9	0.083	Plastic
23	500	44	BI01 L103	0.000	1	0.333	Plastic
23	500	44	L103 180	0.000	1	0.167	Plastic
23	500	44	L203 BI01	5.808	7	0.083	Plastic
23	500	44	L203 BI01	8.100	9	0.333	Plastic
23	500	44	LI01 P103	0.578	2	0.167	Plastic

Load Step	Load Cond	Load Factor	Joint/member/plate	Length (m)	Subseg	Plasticity	Event
23	500	44	P303 LI01	10.326	7	0.083	Plastic
24	500	46	152 L103	2.329	7	0.167	Plastic
24	500	46	152 L103	3.193	9	0.333	Plastic
24	500	46	180 106	0.830	2	0.083	Plastic
24	500	46	180 130	0.649	2	0.167	Plastic
24	500	46	L103 180	0.079	2	0.083	Plastic
24	500	46	LI01 P103	0.000	1	0.333	Plastic
24	500	46	P303 LI01	12.047	8	0.333	Plastic
25	500	48	152 L103	1.897	6	0.083	Plastic
25	500	48	202 L103	7.886	8	0.083	Plastic
25	500	48	BI01 L103	0.545	2	0.333	Plastic
25	500	48	BI01 L103	1.089	3	0.167	Plastic
25	500	48	L103 180	0.159	3	0.083	Plastic
25	500	48	L103 180	0.556	8	0.083	Plastic
25	500	48	L203 BI01	6.954	8	0.333	Plastic
31	500	60	106 105	8.266	8	0.333	Plastic
31	500	60	106 130	2.968	5	0.167	Plastic
31	500	60	106 130	3.710	6	0.250	Plastic
31	500	60	106 130	4.452	7	0.583	Plastic
31	500	60	106 130	5.194	8	0.750	Plastic
31	500	60	107 106	0.000	1	0.333	Plastic
31	500	60	107 106	0.300	2	0.167	Plastic
31	500	60	107 106	0.600	3	0.750	Plastic
31	500	60	107 106	1.120	4	0.667	Plastic
31	500	60	107 106	1.640	5	0.583	Plastic
31	500	60	107 106	2.160	6	0.333	Plastic
31	500	60	107 106	2.681	7	0.250	Plastic
31	500	60	108 W100	0.000	1	0.917	Plastic
31	500	60	108 W100	0.046	2	0.917	Plastic
31	500	60	108 W100	0.092	3	0.917	Plastic
31	500	60	108 W100	0.138	4	0.833	Plastic
31	500	60	108 W100	0.183	5	0.833	Plastic
31	500	60	108 W100	0.229	6	0.833	Plastic
31	500	60	108 W100	0.275	7	0.833	Plastic
31	500	60	108 W100	0.321	8	0.833	Plastic
31	500	60	115 W100	0.000	1	1.000	First hinged occurs

***Table 5.** Energy Structural Absorb - Work Report (KILOJOULES)*

Load			Structure				Ship		Total	
Step	**Cond**	**Factor Joint**	**Work X**	**Work Y**	**Work Z**	**Total**	**Stern**	**Broadside**	**Stern**	**Broadside**
1	BI	1.00 BI01	1.25	5.02	0.00	6.27	0.00	0.00	6.27	6.27
1	BI	Sum Joints	1.25	5.02	0.00	6.27	0.00	0.00	6.27	6.27
2	500	2.00 BI01	10.31	28.27	0.00	38.58	0.00	0.00	38.58	38.58
2	500	Sum Joints	10.31	28.27	0.00	38.58	0.00	0.00	38.58	38.58
3	500	4.00 BI01	27.52	57.85	0.00	85.37	0.00	0.00	85.37	85.37
3	500	Sum Joints	27.52	57.85	0.00	85.37	0.00	0.00	85.37	85.37
4	500	6.00 BI01	52.88	93.76	0.00	146.64	0.00	0.00	146.64	146.64
4	500	Sum Joints	52.88	93.76	0.00	146.64	0.00	0.00	146.64	146.64
5	500	8.00 BI01	86.4	136	0.00	222.39	0.00	0.00	222.39	222.39
5	500	Sum Joints	86.4	136	0.00	222.39	0.00	0.00	222.39	222.39
6	500	10.00 BI01	128.08	184.58	0.00	312.65	0.00	0.00	312.65	312.65
6	500	Sum Joints	128.08	184.58	0.00	312.65	0.00	0.00	312.65	312.65
7	500	12.00 BI01	177.93	239.51	0.00	417.44	0.00	0.00	417.44	417.44
7	500	Sum Joints	177.93	239.51	0.00	417.44	0.00	0.00	417.44	417.44
8	500	14.00 BI01	235.93	300.77	0.00	536.71	139.26	16.61	675.96	553.32
8	500	Sum Joints	235.93	300.77	0.00	536.71	139.26	16.61	675.96	553.32
9	500	16.00 BI01	302.05	368.32	0.00	670.37	481.55	190.87	1151.92	861.24
9	500	Sum Joints	302.05	368.32	0.00	670.37	481.55	190.87	1151.92	861.24
10	500	18.00 BI01	376.21	442.12	0.00	818.33	858.79	382.92	1677.13	1201.25
31	500	Sum Joints	3620.3	3300.86	0.00	6921.16	447587.12	10048.69	454508.31	16969.85
51	500	Sum Joints	6966.01	6698.08	0.00	13664.09	859384.88	15078.73	873049	28742.82

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