RELIABILITY STUDIES ON COMPOSITE COLUMNS USING RELIABILITY INDEX APPROACH

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Abstract - ***Reliability is the capacity of the structure to satisfy the construction specifications outlined under particular circumstances throughout the service life for which it is intended. Different levels of reliability can be established based on the carrying capacity, serviceability, and durability of the construction. The reliability index is one of the greatest ways to illustrate the degree of uncertainty in the notion of reliability. The reliability analysis of CFT is conducted in the present study by FOSM (First Order Second Moment) method to clearly understand the impact of the random features of CFT. The definition of the performance functions is based on the numerical modelling of earlier works of literature and statutory provisions. Reliability index is analysed by FOSM for longer columns (L/D > 12) and for shorter columns (L/D < 12). Probability of failure is calculated for different dimensions of both the columns.***

***Keywords*— Concrete fil1ed steel tubular (CFST), First order second moment (FOSM), First order Reliability method (FORM), second order Reliability method (SORM).**

1. INTRODUCTION

1.1 General

CFST columns are in great demand in construction work because of their small cross-sectional area to load-carrying capacity ratio. With this great feature, the huge concrete columns in tall structures can be replaced by smaller sections of CFST columns. And also, for bridges constructed in a very compact area, CFST elements can serve as piers for bridges. But even though such structural elements must be fully investigated before being used in critical structures, The CFST columns exhibit increased compressive strength as they combine the actions of the steel tube and concrete. The steel section is restricted to local buckling by the concrete core. This CFST column has become increasingly used.

Composite columns are made up of amalgamation of concrete and steel, and make use of the beneficial properties of the component materials. Use of this, reduces the size of column and gives the premium floor space, which can ultimately lead to considerable economic savings. A composite column is a compression component in which the steel and concrete elements act in concert. The concrete core in a composite column resists not only compressive pressures but also buckling of steel components.

1.2 Bond strength of composite columns

The bond strength in the composite columns plays highly recognisable role in the construction. Bond strength essentially influences pressure move in the CFST segment between the concrete center and steel tube. It likewise assumes a significant part in forestalling limited clasping of steel tubes, giving long-lasting formwork, and giving steel-concrete bond strength, guaranteeing that the two unmistakable parts cooperate to endure the different outside loadings of pressure, twist, shear, and bowing second. Accordingly, the structural way of behaving of CFST still up in the air by the bond strength.

Numerous structural advantages come from the concrete poured inside the hollow steel tubes, including enhanced strength due to concrete confinement, less dead load, material savings, and construction that is simpler and quicker than using conventional techniques.

The steel pipe's cross-sectional form, flat width, diameter, or thickness, slenderness ratio, concrete core strength, and the steel pipe's local buckling behaviour are all contributing elements to the rise in strength.

1.3 Steel and concrete working together as a composite

A helpful explanation of the compound activity of concrete and steel is provided by the display of sections under hub pressure. There is a separation between the steel wall and the concrete centre because the poisson's proportion for concrete is lesser than that for steel during the underlying stages of stacking. According to Furlong [1], the poisson's ratio of concrete similarly rises with the load, from 0.15 to 0.2 in the elastic range to 0.5 in the inelastic range.

1.4 Concrete Confinement

Concrete confinement is the three-dimensional stress state that forms under an axial load and increases strength as a result of the development of radial pressure at the steel-concrete contact.

Concrete confinement has a more noticeable effect on circular sections because membrane type buckling causes them to fail, whereas it has little to no effect in rectangular sections. Since the steel tube encircling the concrete core in circular portions acts as lateral restraint, full contact between the steel and concrete occurs, increasing strength. According to Von Mises' yield criterion, this gain offsets the decrease in steel's yield strength in compression caused by the hoop tension required to confine concrete. Due to plate buckling, hoop stress created in rectangular portions varies along the sides. The confining effect is lessened as a result.

The confinement effect is lessened due to the rise in slenderness also in circular sections.

1.5 Concrete Core Strength

The stiffness of CFT columns is determined by the concrete's core strength. Although columns those are filled with high strength concrete display brittle behaviour and crush when loaded, stiffness rises as concrete core strength increases. Additionally, according to O Shea and Bridge [5], stiffness loss for high strength concrete in filled tubular columns happens quickly and occasionally with axial strain reversal. But it is a truth that filled columns become highly strong to a greater extent as the strength of the concrete core rises.

2. RELIABILITY STUDIES

2.1 Reliability

The potential that a system or component will carry out its intended performance correctly for a predetermined amount of time under predetermined operating conditions is known as reliability. The failure rate or the hazard rate is a crucial component of reliability analysis because it gives an indication of how the probability of failure evolves throughout the course of a component's lifetime. In actual use, it frequently takes the shape of a bathtub. The reliability assessment process involves choosing a reliability model, analysing the model, calculating the reliability performance indices, and evaluating the results, which includes deciding whether to make adjustments.

2.2 Reliability Index

Since it is expected that both the resistance provided by a system "R" and the load measurements on the system "S" vary, M = R -S will also show fluctuation. The dependability index 'β' is known as the ratio between the mean value of the M function (μM) and the standard deviation of the M function (σM). If 'M' has a normal distribution and if 'Φ' is the cumulative distribution function, then β = -Φ(1-Reliability) = μM / σM.

2.3 Most Probable Point of Failure

The Most Probable Point (MPP) is also known as the point on the limit state that is furthest from the origin in conventional normal space.

Pf = Φ (-β) (1.1) yields the first-order reliability estimate.

Where 'Φ' is the standard normal variable's cumulative distribution function and 'β' is the distance from the origin to MPP. Different methods can be used to determine the most likely point (MPP). Figure 3.1 makes it obvious that the estimated MPPs fall within the target reliability range.

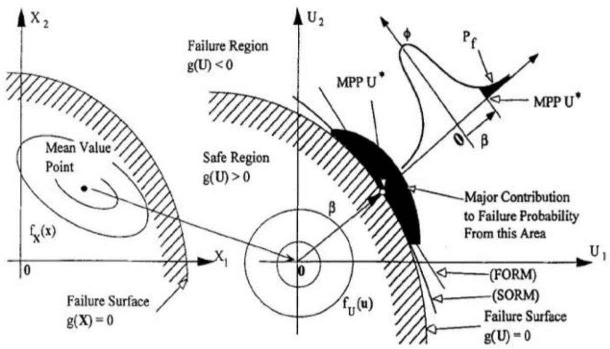

Fig: 3.1 most probable point of failure

2.4 Uncertainties in Civil Engineering and Its Resources

Despite the uncertainties in the many factors employed in the study and design of the structure, it is very difficult to calculate the absolute safety of the structure using deterministic analysis. Therefore, one of the most important approaches to offer a justification for a safety requirement for a building is to evaluate its dependability or likelihood of failure. A popular definition of reliability is the possibility that a structure will continue to serve its original purpose. Failure of a structure is a generic term that doesn't always mean major failure, but rather that the structure doesn't work as intended, the possibility of failure is used as a measurable indicator of safety factor in calculations involving structural reliability.

Various uncertainties plague the design process in civil engineering. Some of their hidden traits can be easily distinguished, while others cannot. Stochastic and uncertainty in implementing systems and its components are two categories of uncertainty in civil engineering. The first group is probabilistic, but the other group depends on human understanding of the behaviour of the entire system and its constituent parts. The five groups that make up the most significant source of uncertainties in civil engineering are as follows.

1. Uncertainty in loading
2. Uncertainty in resistance
3. Uncertainty in modelling
4. Uncertainty in selecting the designing codes
5. Human error

3. RELIABILITY METHODS

The reliability technique, according to JCSS, can be divided into three categories. All semi-probabilistic methods, such as the semi-probabilistic safety concept, are summarised at level 1. The idea is the methodological underpinning of structural engineering standards and norms. To ensure the necessary level of reliability, it makes use of part of safety considerations and characteristics of materials and operations. There can be no distribution functions utilised, and level 1 is expected to use linear limit state functions. 1st and 2nd order reliability theories (FORM/SORM) establish level 2 technique. The techniques are applied to level 1 code calibration. Probabilistic techniques including numerical integration, stochastic simulation, Monte Carlo, and others are included at level 3.The methods are employed to rate the level 1 and level 2 models. For direct structural studies, level 2 and level 3 methods can be utilised, although due to their complexity, they are rarely used. When conventional approaches cannot give the analyses, or when the current margin of safety need to be precisely calculated, the application of the methodologies makes sense.

The point state "g(X)=0" is oftentimes linearized by means of the Taylor series development. In this strategy, constancy is assessed utilizing the 1st or 2nd request Taylor series development. The First Order Second Moment (FOSM) and Second Order Second Moment (SOSM) approaches, individually, are the names of these procedures.

4. Reliability Analysis

Reliability and probability of failure are calculated by FOSM (First Order Second Moment) method for longer and shorter columns by taking L/D ratio as:

Longer columns, L/D > 12

Shorter columns, L/D < 12

According to Eurocode -4

Limit state function is

G(θE x E, θR x R)= θR x R- θE x E

Where

E- Random variables for action effects.

R- Random variables for resistance of structural member.

Design buckling resistance of composite column

Rd = k {(AsFy/γm) + (0.875AcFck/γc)}

As- Area of steel tube,

Ac- area of concrete,

Fy- yield strength of steel,

Fck- compressive strength of concrete,

γm&γc- partial safety factor,

Table: Statistical parameters of random variables

Category Of Variables	Variables	Distribution	Mean Value μ_x	Standard Deviation Σ_x
Model Uncertainty	Action Effect Factor (Θ_e)	Normal	1	0.10
	C/S Area (A)	Normal	μ_a	0.02 μ_a
	Yield Strength (F_y)	Log-Normal	F_y+2 Σ_x	30
	Compressive Strength (F_{ck})	Log-Normal	F_{ck}+2 Σ_x	5
	Resistance Factor For CFT (Θ_r)	Normal	1.10	0.14 μ_q
Actions	Permanent (G)	Normal	G_K	0.1 μ_g

4.1 Reliability Analysis by Using First Order Second Moment (FOSM) Method

Data:

- Outer dia of the tube = 33.7 mm
- Thickness = 2.9 mm
- Inner dia of the tube = 30.8 mm
- Length = 300 mm
- Fck = 23.93 N/mm^
- Fy = 310 N/mm^
- Pcr = 123000 N
- γm = 1.15
- γc = 1.5
- Area of Steel (As) = 146.83425 mm^2
- Area of Concrete (Ac) = 744.6824 mm^2

According to Euro code,

Performance function is, M = R – S

M = margin of safety

R = capacity of column

S = Demand

M= θR((As x Fy /ɣm)+ (0.85*Ac*Fck/ɣc))- θE* Pcr

Where:

As/ɣm = 127.6819565

0.85*Ac/ɣc = 421.9866933

θR = Resistance factor for CFST

θE = Action effect factor

Consider:

θR= x1 Fy=x2 Fck=x3 θE=x4

M= (As/ɣm)*x1*x2+ (0.85*Ac/ɣc)*x1*x3-x4*Pcr

μm = -57107.88282

σR = 19688.52151

Reliability Index (β) = μm/σR = -2.900567358

Probability of Failure, From Z Table for 0%

Pf = 0.187%

5. RESULTS

Further results are tabulated for longer columns (L/D>12) and shorter columns (L/D<12). Graphs are ploted accordingly.

Table: Reliability Index by FOSM Method - Longer Columns (L/D > 12)

SL no	Diameter mm	Thickness mm	Length mm	Reliability Index by FOSM (First Order Second Moment Method)
1	33.7	2.6	300	-1.24
2	33.7	2.6	300	-1.5
3	33.7	2.6	300	-1.43
4	33.7	3.2	300	-1.23
5	33.7	3.2	300	-1.23
6	33.7	3.2	300	-1.16
7	33.7	4	300	-1.2
8	33.7	4	300	-1.25
9	33.7	4	300	-1.21
10	42.4	2.6	300	-1.29
11	42.4	2.6	300	-1.39
12	42.4	2.6	300	-1.29
13	42.4	3.2	300	-1.12
14	42.4	3.2	300	-1.18
15	42.4	3.2	300	-1.11
16	42.4	4	300	-1.04
17	42.4	4	300	-1.12
18	42.4	4	300	-1.06
19	48.3	2.6	300	-1.24
20	48.3	2.6	300	-1.29
21	48.3	2.6	300	-1.18
22	48.3	3.2	300	-0.95
23	48.3	3.2	300	-0.96
24	48.3	3.2	300	-0.91
25	48.3	4	300	-0.83
26	48.3	4	300	-0.86
27	48.3	4	300	-0.83

Table: Reliability - Longer Columns (L/D > 12)

1	33.7	2.6	300	0.89251	89.25
2	33.7	2.6	300	0.93319	93.32
3	33.7	2.6	300	0.92364	92.36
4	33.7	3.2	300	0.89065	89.07
5	33.7	3.2	300	0.89065	89.07
6	33.7	3.2	300	0.85543	85.54
7	33.7	4	300	0.88493	88.49
8	33.7	4	300	0.89435	89.44
9	33.7	4	300	0.88686	88.69
10	42.4	2.6	300	0.90147	90.15
11	42.4	2.6	300	0.91774	91.77
12	42.4	2.6	300	0.90147	90.15
13	42.4	3.2	300	0.86864	86.86
14	42.4	3.2	300	0.881	88.10
15	42.4	3.2	300	0.8665	86.65
16	42.4	4	300	0.85083	85.08
17	42.4	4	300	0.86864	86.86
18	42.4	4	300	0.85543	85.54
19	48.3	2.6	300	0.89251	89.25
20	48.3	2.6	300	0.90147	90.15
21	48.3	2.6	300	0.881	88.10
22	48.3	3.2	300	0.82894	82.89
23	48.3	3.2	300	0.83147	83.15
24	48.3	3.2	300	0.81859	81.86
25	48.3	4	300	0.79673	79.67
26	48.3	4	300	0.80511	80.51
27	48.3	4	300	0.79673	79.67

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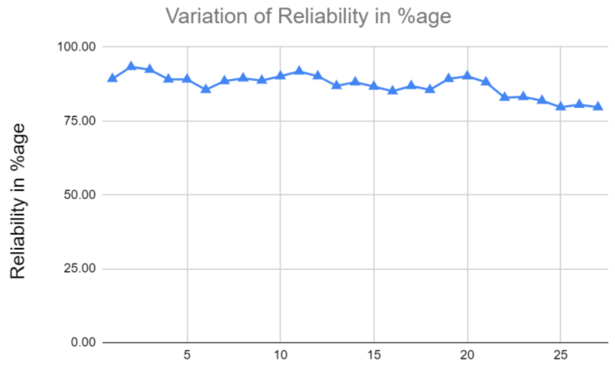


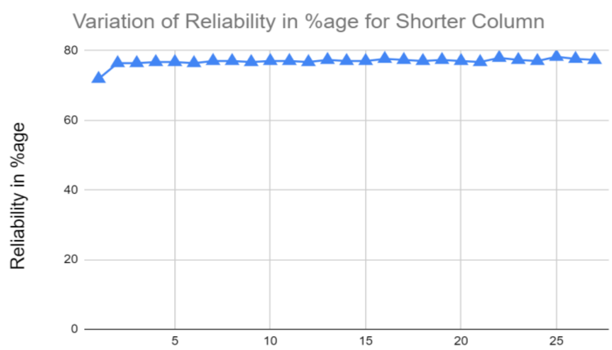
Graph: Variation of Reliability- Longer Columns (L/D > 12)

Table: Reliability Index by FOSM method- Shorter Columns (L/D <12)

Sl No	Diameter mm	Thickness mm	Length mm	Reliability Index by FOSM (First Order Second Moment Method)
1	33.4	1.65	135	-0.58
2	33.4	2.11	201	-0.72
3	33.4	2.77	268	-0.72
4	33.4	1.65	135	-0.73
5	33.4	2.11	201	-0.73
6	33.4	2.77	268	-0.72
7	33.4	1.65	135	-0.74
8	33.4	2.11	201	-0.74
9	33.4	2.77	268	-0.73
10	42.2	1.65	170	-0.74
11	42.2	2.11	254	-0.74
12	42.2	2.77	338	-0.73
13	42.2	1.65	170	-0.75
14	42.2	2.11	254	-0.74
15	42.2	2.77	338	-0.74
16	42.2	1.65	170	-0.76
17	42.2	2.11	254	-0.75
18	42.2	2.77	338	-0.74
19	48.3	1.65	194	-0.75
20	48.3	2.11	290	-0.74
21	48.3	2.77	387	-0.73
22	48.3	1.65	194	-0.77
23	48.3	2.11	290	-0.75
24	48.3	2.77	387	-0.74
25	48.3	1.65	194	-0.78
26	48.3	2.11	290	-0.76
27	48.3	2.77	387	-0.75

Table: Reliability - Shorter Columns (L/D <12)

Sl No	Diameter mm	Thickness mm	Length mm	Reliability	Reliability in %age
1	33.4	1.65	135	0.71904	71.904
2	33.4	2.11	201	0.76424	76.424
3	33.4	2.77	268	0.76424	76.424
4	33.4	1.65	135	0.7673	76.73
5	33.4	2.11	201	0.7673	76.73
6	33.4	2.77	268	0.76424	76.424
7	33.4	1.65	135	0.77035	77.035
8	33.4	2.11	201	0.77035	77.035
9	33.4	2.77	268	0.7673	76.73
10	42.2	1.65	170	0.77035	77.035
11	42.2	2.11	254	0.77035	77.035
12	42.2	2.77	338	0.7673	76.73
13	42.2	1.65	170	0.77337	77.337
14	42.2	2.11	254	0.77035	77.035
15	42.2	2.77	338	0.77035	77.035
16	42.2	1.65	170	0.77637	77.637
17	42.2	2.11	254	0.77337	77.337
18	42.2	2.77	338	0.77035	77.035
19	48.3	1.65	194	0.77337	77.337
20	48.3	2.11	290	0.77035	77.035
21	48.3	2.77	387	0.7673	76.73
22	48.3	1.65	194	0.77935	77.935
23	48.3	2.11	290	0.77337	77.337
24	48.3	2.77	387	0.77035	77.035
25	48.3	1.65	194	0.7823	78.23
26	48.3	2.11	290	0.77637	77.637
27	48.3	2.77	387	0.77337	77.337



Graph: Variation of Reliability- Shorter Columns (L/D < 12)

6. CONCLUSIONS

- The difference between the analytical and codal results for longer and shorter CFT columns demonstrates the suitability of the design.

- The CFT columns are strong enough to withstand the imposed loads, and experimental and analytical findings will be consistent.
- Reliability Index analysed by FOSM method for longer columns increases as increase in diameter and thickness of column, whereas, for shorter columns remains almost constant.
- When the steel tube's thickness is increased while other factors such as concrete grade, steel grade, length, and diameter remain constant, the probability that the CFT column will fail increases.
- The probability of the CFT column failing decreases as concrete quality in the steel tube increases, keeping other factors such as length, diameter, and thickness unchanged.
- The probability of the CFT column failing increases with an increase in steel tube diameter at constant concrete grade, steel grade, length, and thickness.

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