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Service Design Intervention in Marine Jetty

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Abstract

A jetty can be defined as a structure which is constructed upon water bodies which facilitates mooring of boats and ships. The structure is usually made up of concrete and wooden planks. As the WL changes in rivers, there is a height variation seen between the jetty and boat. This led to further difficulties and accidents while boarding and de-boarding the boat. However, the designed structure should be effective in both the climatic conditions – summer and rainy, irrespective of change in water levels in the rivers. There is no any proper design yet found for the mooring of ships and boats rather than the ancient existing technique. Therefore, in this paper, I would like to find **Service Design Intervention in Marine jetty** in order to meet the requirements of the users, irrespective of change in WL of rivers and satisfying the passenger experience by making the design more tangible.

KEYWORDS : Jetty structure, Design intervention in marine jetty, height variation in marine, water level in marine, boarding boat, de-boarding boat, summer water level, water level difference, passenger experience, boat journey, boat jetty, Kerala boat services.

Abbreviations

- PCD - Passenger Count Data
- E-waste - Electronic waste
- FK – Fort Kochi
- ERN – Ernakulum
- GR – Graphical Representation
- WL – Water level
- IMD - India Meteorological Department
- CWC - Central Water Commission
- DPR – Detailed Project Report
- KSEB - Kerala State Electricity Board

Introduction

Marine jetties act as a parking bay for boats and ships. The structure is usually made up of concrete and wooden planks. As the WL in the river changes, there is a height variation seen between the jetty and boat. This leads to further difficulties and accidents caused by the people while boarding and de-boarding the boat.
Studies have shown that during extremely hot weather season in Kerala, the water in the rivers falls up to 1 m and during monsoon, the water increases to a certain level. In both these cases, the heights between the jetty and boat become a problem for the people to board and de-board from the boat. They often need external supervision to board and de-board the boat. In some extreme cases, people fell into the river, drop their belongings when they enter the boat, more time consuming when there is a crowd, etc.

Tourist boat jetty, Marine Drive

However, no solution is found so far on this topic. In this thesis, the problem is dealt with the passenger safety, comfort and stability of the structure. A re-design or a substitute for the Marine jetty is found out in order to solve the problem.

Methodology

There are various procedures that are followed by any researcher in order to identify the problem, understanding every possible way to solve the problem, analysing it and generating the concepts, process and analyse information applied to understand the problem. It involves obtaining data from existing documents without having to question people through interview, questionnaires or observe their behaviour.
In this research, I have adopted questionnaire (online and offline), interviews, direct observations, photography, and videography. The initial level of desk research was also done. (References are mentioned). Other quantitative data was collected from the India Meteorological Department (IMD), Central Water Commission (CWC) and Kerala State Electricity Board (KSEB).

Observations

It can be in the form of quantitative or qualitative research. For instance, if I want to determine the number of people entering and getting out of the boat, I need to take a quantitative analysis.

If I want to know the difficulty faced by the people while entering the boat from a jetty or vice-versa, I will have to spend time observing and describing the reactions of the people which is, therefore, a descriptive data and would be qualitative.

Quantitative Analysis

Passenger Count Data (PCD)

It provides insights into passenger behaviour for managing passenger flows in the boat jetties and on boats, ensuring the customer needs and difficulties faced by them across the networks. However, there are 6 main Boat Stations in Cochin coast.

The number of passengers traveling at various boat timings was collected from the ticket counter of each station. The passenger flow was recorded daily at every station. This helps in predicting the maximum and minimum passengers, using the boat service based on the relevance.

Rainfall Pattern

Rainfall pattern play a major role in construction, especially in marine field which includes outdoor construction. As a result, weather conditions should be taken into consideration. Climatic conditions play a major role in the stability, design, and performance of the structure. The rainfall pattern of the site over a past 5 years (minimum) has to be studied and the structure should be designed as per the inference.

Qualitative Analysis

Direct Observation

Direct observations must be done in order to find more insights from the passenger perspective. Rather than the desk research, a directly observed data becomes more powerful and validating. This enables us to find out the exact problems, difficulties while boarding/de-boarding the boat, in-depth perspectives, body language of the people, present scenario of the jetties, etc. All these must be recorded in the form of short notes, photographs and video graphs for future research, evaluation, and inference.

Site Investigation

While designing a marine structure, it is very important to study the nature of the soil. This helps in deciding the design and material to be used based on the stability provided by the soil. However, the information is to be collected from the IMD.

Questionnaires

Questionnaires can be used to collect both quantitative and qualitative data. A well-developed questionnaire can be distributed to a much larger crowd which is not possible in an interview. They are particularly well suited for research seeking to measure some parameters for a group of people or to make comparisons between groups of people, i.e. interviewing people by

classifying them based on age, education, frequent and regular travellers and tourists. Questionnaires will be done online and offline.

Online Survey

The questionnaire was prepared for an online survey for the people in Kerala. The following details were collected:

- Basic details – name, age group, sex
- Whether they use boat service and how often
- Purpose of boat service
- Whether they use boat service during the rainy and dry season
- Whether they use boat service if there is a change in WL
- Experience of slippery issues while boarding and de-boarding from the boat jetty
- Whether there was a requirement of Re-designing the existing boat jetty

Offline Survey

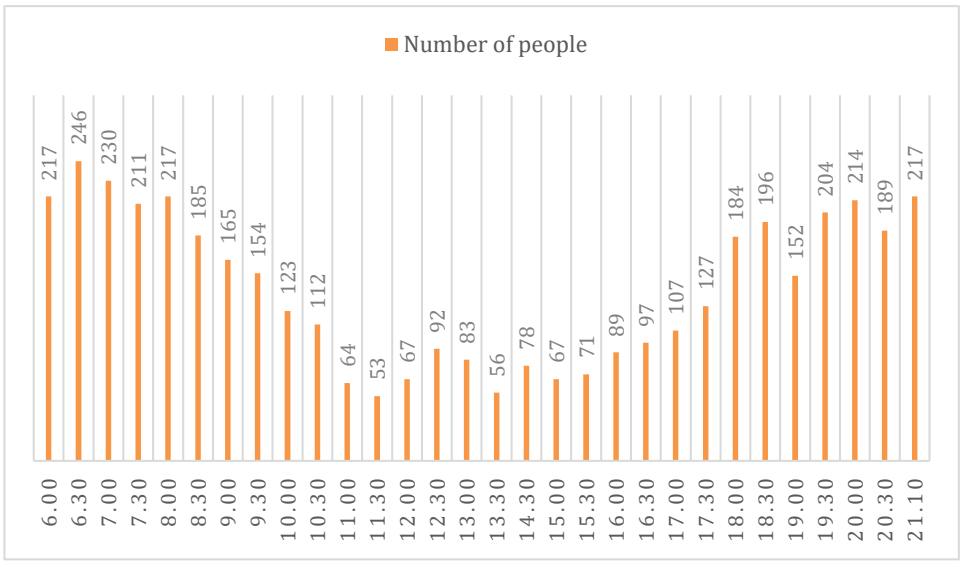
The following tasks were performed:

- Interviews were done to find the insights- asking questions about the personal experience about the boat services, their perspectives, digging deeper about the feeling and emotion, and moreover, the passengers were given a chance to talk about anything about their travel, etc.
- Their emotions, facial expressions, accidents if any, etc were noted down for further references

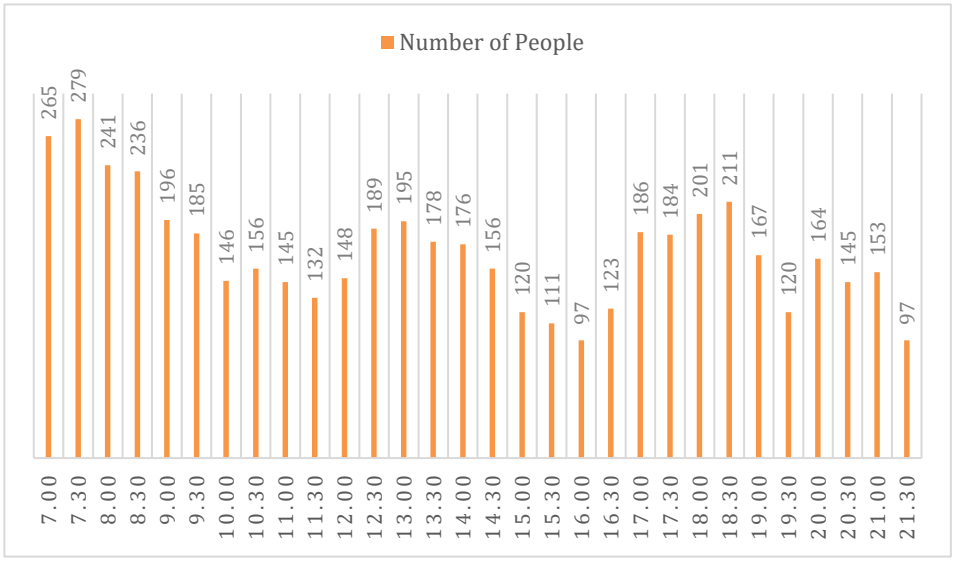
Results

PCD result

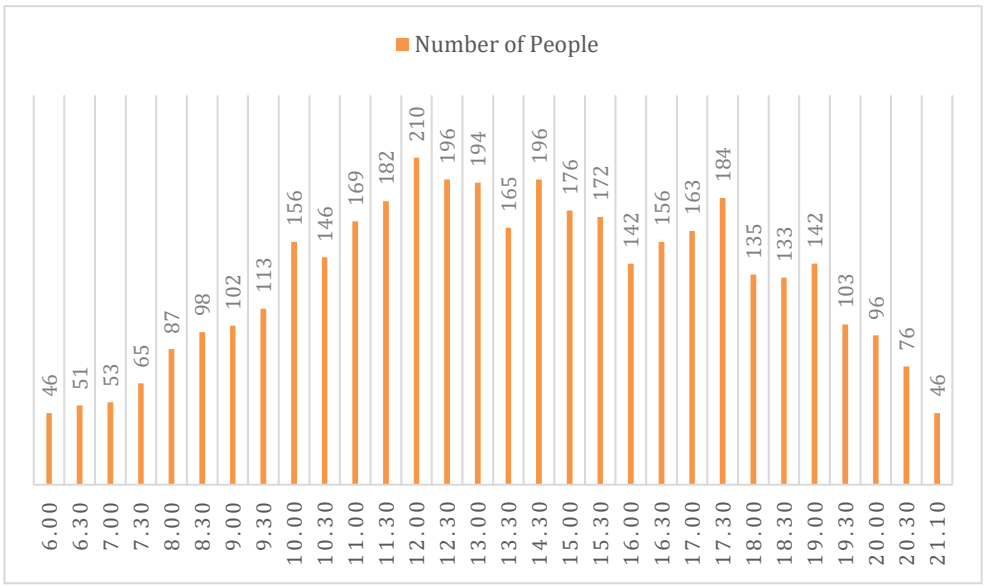
- It was found that there is an average number of 170 people (approx.) has been using the boat service at a time with a maximum value
- It was also found that an average number of 135 people (approx.) has been using the boat service at a time with a minimum value
- However, from the above data, it shows that people are still dependant on the boat services on a regular basis as a means of transport



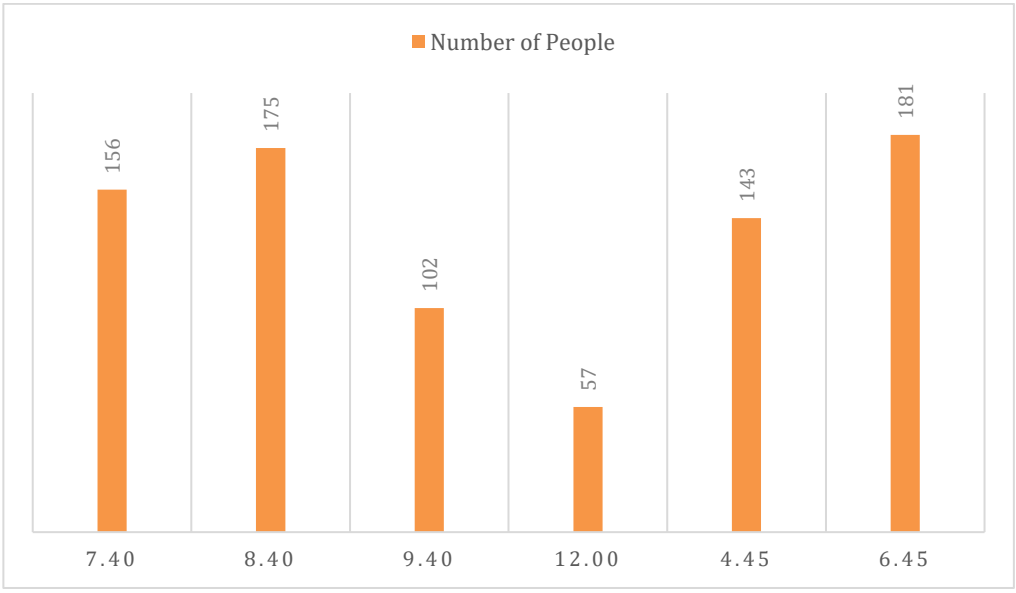
PCD of ERN jetty to FK jetty



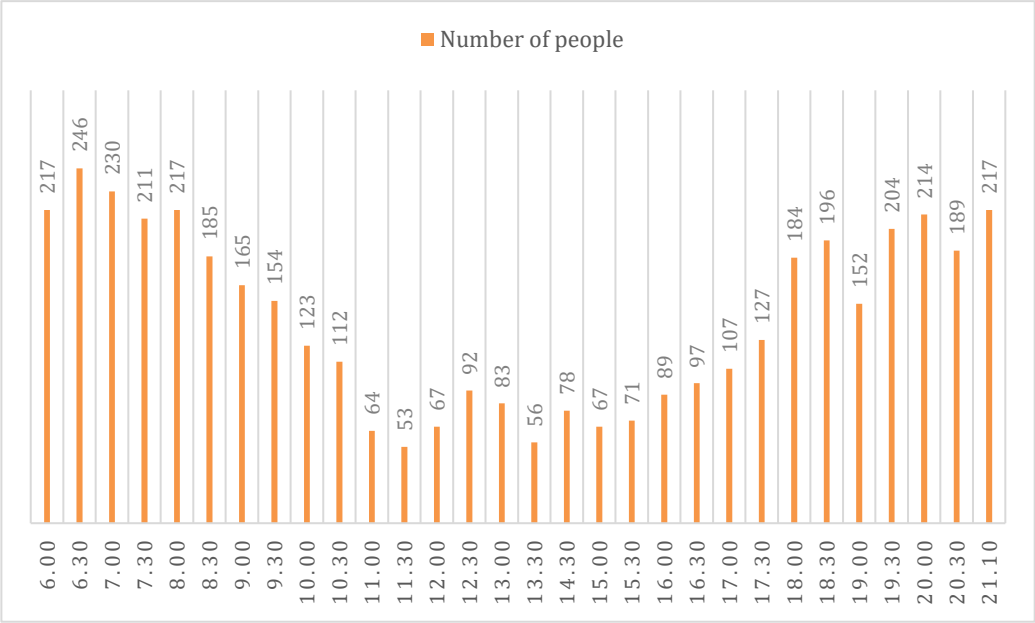
PCD of ERN jetty to Vypeen jetty



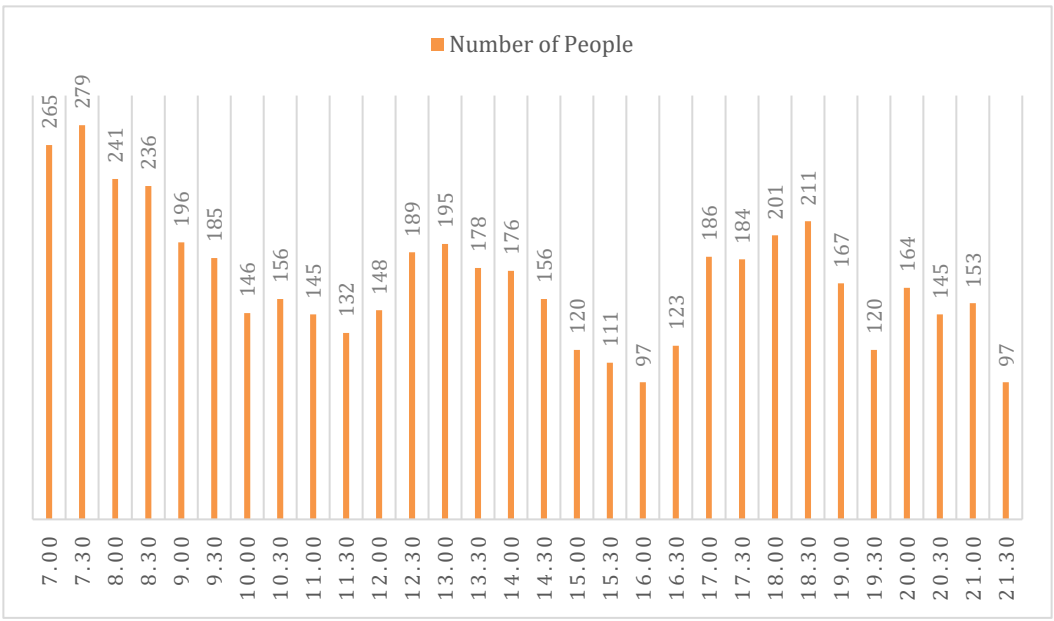
PCD of ERN jetty to Mattancherry jetty



PCD of ERN jetty to Varapuzha jetty



PCD of Highcourt jetty to Bolgatty island

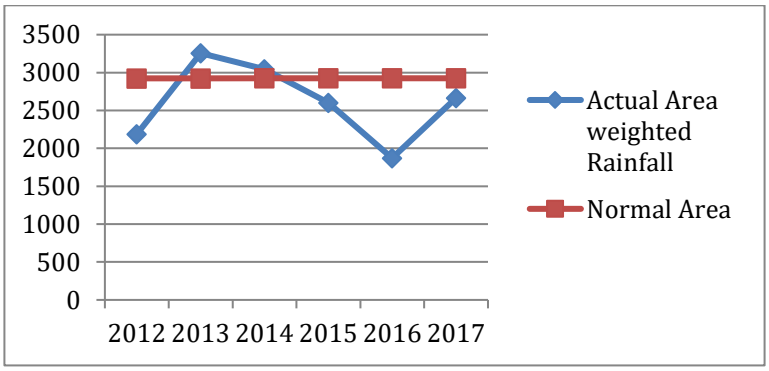


PCD of FK jetty to Highcourt jetty

Rainfall pattern

YEAR	ACTUAL VALUE	NORMAL VALUE
2012	2187.5	2923.4
2013	3255.4	2923.4
2014	3046.4	2924.3
2015	2602.9	2924.3
2016	1870.9	2924.3
2017	2664.9	2924.3

All Kerala Area weighed under rainfall (in mm)



GR of area weighed under rainfall

- It was found that Kerala is a monsoon prone state and it receives a good rainfall during monsoon
- However, the rainfall pattern is not constant. Sometimes they increase than the expected normal value and, in some cases, they decrease than the expected normal value

Direct Observation

Present scenario of High court jetty

Observation from High court jetty

- The distance between the jetty and the boat creates difficulty for the passengers of all age groups
- Possibilities of accidents – falling when boarding and deboarding while at hurry, with babies, luggage, elderly, etc
- More time consumption while boarding and deboarding

Tourist jetty, Marine Drive

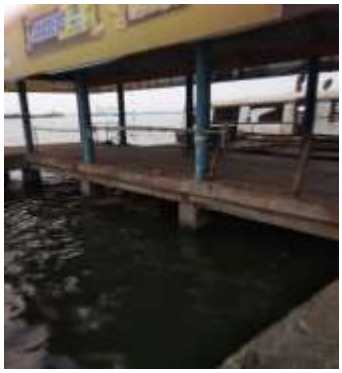
Observation from Tourist jetty

- There is a comparable difference in height between the jetty and the boat
- The structure is not stable
- People find it unsafe because of the structure stability, no handrails and hence more possibility for accidents
- Due to tidal force, there is a wear and tear on the structure and thereby reducing the stability

Fort Kochi jetty observation

Observation from Fort Kochi jetty

- The platform becomes unsafe when there is more crowd as there is no handrails or parapets provided along the edges
- If there are more tides, there are possibilities for the water entering the jetty and again causing difficulties for the passengers while boarding and de-boarding



Present scenario of Fort Kochi jetty

- Pregnant ladies, women carrying children, kids, elderly and physically handicapped find it more unsafe when there is a difference in height
- No shelter. During a rainy day, the jetty becomes wet and people need to be more cautious from slippery issues

Ponnarimangalam jetty

Observation from Ponnarimangalam jetty

- Due to the salinity in the river, the piles of this jetty have been corroded
- The structure has become less stable because of the deterioration of the concrete
- The width of the jetty is comparatively less and hence it creates an issue when there is more crowd. Hence the chance of accidents is more

Present scenario of Mattancherry jetty

Observation from Mattancherry jetty

- There is more space between the jetty and the boat and thereby leading to unsafe boarding and de-boarding
- There is no side protection or handrails which ensures safety while boarding and de-boarding

Observation from Shadowing a boat journey

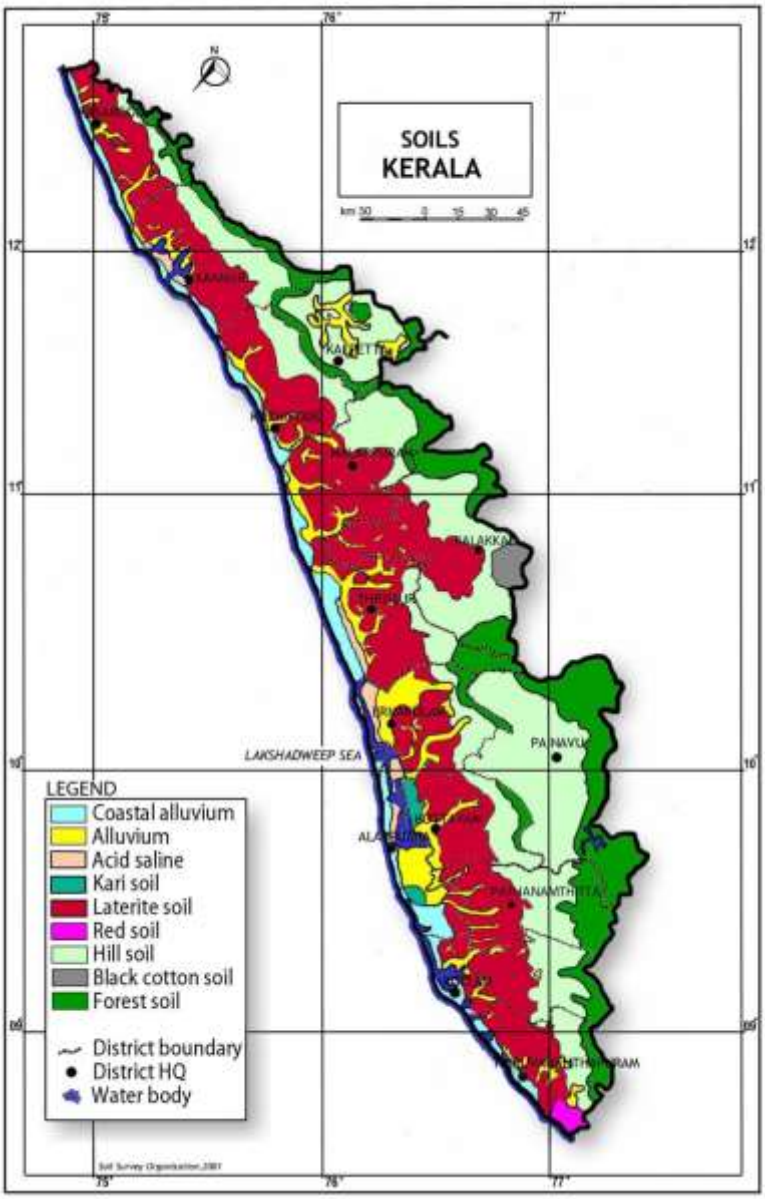
- Horizontal and Vertical distance variation between the jetty and the boat were observed and as a result, leading to awkward positions while boarding and deboarding
- Most of the people wanted external support while entering the boat (lending hands of other passengers) as there were no provided on the jetty

Shadowing passenger experience

- More difficulties were observed when the elderly had to enter the boat
- Videos were also taken to study the passenger insights
- Pregnant ladies, women carrying children, kids, elderly and physically handicapped find it more unsafe when there is a difference in height

Site investigation

It was inferred that most of the soil in Kerala was mainly Acid saline, Alluvium, and Laterite soils. The data was collected from the IMD and the strength and stability of the soils were studied.



Soils of Kerala India Meteorological Department (IMD)

Acid saline soils are mainly present in Ernakulum, Thrissur and Kannur districts. The speciality of these soils is that they are waterlogged and are ill-drained areas. The land is saline because of the presence of Arabian Sea. However, during rainy season, the rain water enters the rivers and the salinity of the rivers are reduced. The colour of the soil was noticed as dark grey to black colour.

Laterite soils are formed after so many mineral transformations and weathering. As a result, the iron content in these soils are very high.

Fluvial sediments of marine, lacustrine and riverine sediments combine to form alluvium soils. They are generally found below 20m MSL in the lowland plains, basins, valleys and along the banks of major rivers. These soils are mainly found in Alappuzha and adjacent lands of Thrissur district. The soils are frequently flooded and submerged.

Questionnaire

The responses got after questionnaire about people using boat service on a dialy basis was 50% and 30% used once/twice a week and 20% used for tourism. On daily basis, majority were students. The responses got after questionnaire about people using boat service during rainy season was 70%. Only 50% of people uses the service when there is less water in rivers, most of them are scared to use it during such climatic conditions. The responses got after questionnaire about people about facing the difficulty while boarding/de-boarding the boat is 95% and about 99% of people strongly recommended for a Design Intervention for the Marine structure.

Insights obtained from live interviewing and shadowing

- Most of the time, there is a crowd when people are boarding and de-boarding the boat. As there are no side protection or handrails, 90% of the people need supervision from the boat staff.
- Many people have experienced serious accidents such as: falling into the river when there is a huge height variation due water-levels in rivers, hitting their head on the main slab of the jetty or on the boat.
- Dropping of valuables and luggage into the river while boarding or de-boarding.

People waiting for boat at Bolgatty boat jetty

- Most of the people are scared to use the boat service when they are in a hurry because it has often led them to slip or even fall into the river.
- The time consumed by the passengers to enter the boat is more when there is a crowd. Free and easy moving is not possible as they are scared that they would fall into the river.

- Mothers fear to leave their children alone to jetty as there is no side protection. This creates a fascination for children when they see a closer view of rivers where they can play in the water by simple bending and leaning across the edges of jetties.
- When there are heavy tides, the water enters the jetties quite often and thereby leading to slippery issues, accidents and affects the stability of the structure.
- Many people are fond of fishing in Cochin coast and it has been noticed that people sitting on the edges of the jetty by putting their legs into the river which is unsafe. This happens because there is no side protections or parapets provided along the edges of the jetties.

Discussion

- Number of passengers travelling at different time intervals was plotted graphically. Average usage of boat services per day was obtained. The maximum value was 170 people and the minimum value was 135 people. A structure is to be designed which is capable to freely move a minimum of 200 people at a time without causing rush.
- Annual area weighted rainfall of past 6 years of Kerala was collected. Cochin coast is monsoon prone land and as a result, the structure designed should be more water resistant and durable.
- Sediment deposition accumulation in Cochin coast was of normal value. Re-design must be done only on the structure, as navigation path of the coast was normal and sediment protection to the jetty was not needed.
- Existing boat jetties were badly affected by the saline content in river. The structure was more unsafe and stable. People faced difficulty while boarding and de-boarding because of safety issues. So the structure which is to be designed should be resistant to acid and alkaline. It should be durable and must withstand extreme climatic conditions.
- Safety aspects while boarding, de-boarding irrespective of change in height between jetty and boat, easy moving of the crowd within jetty, safeguard implementation should be considered in the design.
- Online questionnaire was conducted, and responses were plotted graphically. Interviews were conducted targeting the users. More insights were found out which further helped in ideating the design with the needs and requirements of the users.

Problem Area

There is no proper design yet found for the mooring of boats rather than the ancient existing design. I have considered places in Kerala (state), India (country) for this Research paper. However the condition is same across all over the world (based on desk research and case studies). In this paper, I would like to overcome the following problems in the service design of Marine jetties for a better design that would enhance the passenger experience with less or no risks.
The following problems where concluded:

- People find it difficult to board and de-board the boat to the jetty when there is a difference in water-level in rivers.
- Using boat services during the extreme summer season and rainy season have been reported as unsafe. Accidents are found during entering and leaving the jetty due to change in WLs in rivers.
- There is no design intervention done so far in the structure of the Marine Jetty.
- Alterations are done on the system based on the requirements to make the work easier.
- The existing structure is the same, only specifications are changed based on the requirements.

Concept generation

Based on the findings and problem identification, considering the user requirements and needs, rough concepts where generated. Brainstorming was done on the ideations and detailing was done for the concepts. A proper design incorporating the features were made on a CAD model and the effective best three concepts where chosen.

Concept I: Floating deck using concepts of Fluid mechanics

- The structure is immersed in a river up to a depth
- A part of the structure will be above the WL as shown
- Based on the tidal currents, the water enters inside the T pipe and due to the pressure, the water enables the main slab to move upwards
- This is much like that of the working of a reciprocating pump with a plunger. The plunger moves up as the water enters through the inlet. Later, the plunger moves downwards, thereby flushing the water through the outlet valve
- The above-mentioned process happens in case of this jetty. This thereby enables the jetty to remain floated based on the WL of the river
- However, the main slab is attached to the T-pipe with a telescopic pipe. So that the main slab does not displace from the base after a level

Concept II: Floating structure with I-sections and cantilevered at one end

- The structure is fixed at one end i.e. it is partial floating on the river
- The main deck is fixed at one end on land and the other end is free floating on the river

- It is fixed on one end at a height on land where the maximum level of water in the river rises
- The deck moves in a vertical direction based on the increase and decrease in the WL
- The base of the structure is supported using I-sections
- The force exerted on the deck is transferred via I sections in an equal manner and enables more stability upon the river
- This also prevents the structure from tidal currents as it is structurally stable by the centre of gravity
- There are handrails provided on the centre to ensure safe boarding and de-boarding

Concept III: Concrete structure (static) with E-waste

- It is a concrete structure incorporating steps at three different levels based on WLs
- The structure is made of concrete were a certain percentage of the aggregates are replaced

Concept selection

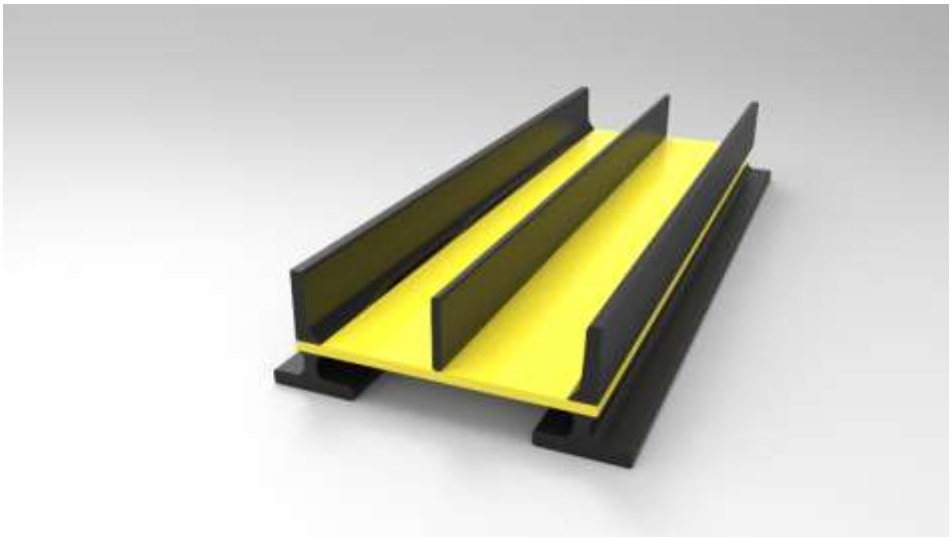
Concept selection was done using PUGH's decision matrix method. Concept II (Floating structure with I-sections and hinged at one end) has been selected as the final as shown below. Modifications and detailing will be done to the concept based on further brainstorming and inferences obtained from the testing.

*Datum was considered as the existing design of boat jetties.

CRITERIA	DATUM*	CONCEPT I	CONCEPT II	CONCEPT III
Max. Load bearing Capacity	0	+3	+3	+2
Temperature resistance	0	+3	+3	+2
Acid/ Alkaline resistance	0	+1	+3	0
Strength (shear & tensile)	0	+3	+3	+2
Compatibility	0	+1	+3	+2
Toughness	0	+3	+3	0
Density variation	0	+1	+2	+3
Weight	0	+2	+3	0
Environmental stability	0	0	0	+3

Handling	0	+3	+3	+1
Future scope	0	+2	+2	+2
Safety	0	+2	+2	+3
Life span	0	+3	+3	+1
Cost	0	+1	+1	+1
Total ∑ =	**0**	**28**	**34**	**22**

Concept selection using PUGH's Decision matrix



Floating structure with I-sections and hinged at one end

Working of the Concept

- The structure is fixed at one end i.e. it is partial floating on the river
- The main deck is fixed at one end on land and the other end is free floating on the river
- It is fixed on one end at a height on land where the maximum level of water in the river rises
- The deck moves in a vertical direction based on the increase and decrease in the WL
- The base of the structure is supported using I-sections
- The force exerted on the deck is transferred via I sections in an equal manner and enables more stability upon the river
- This also prevents the structure from tidal currents as it is structurally stable by the centre of gravity
- There are handrails provided on the centre to ensure safe boarding and de-boarding

Material selection

General steps in materials selection are as follows:

- Based on the performance
- An alternative solution to the problem
- Permutation - Combinations of the different solutions
- Decision on the most precise solution

Based on the functional requirements of the material for the Concept II, certain material explorations were done.

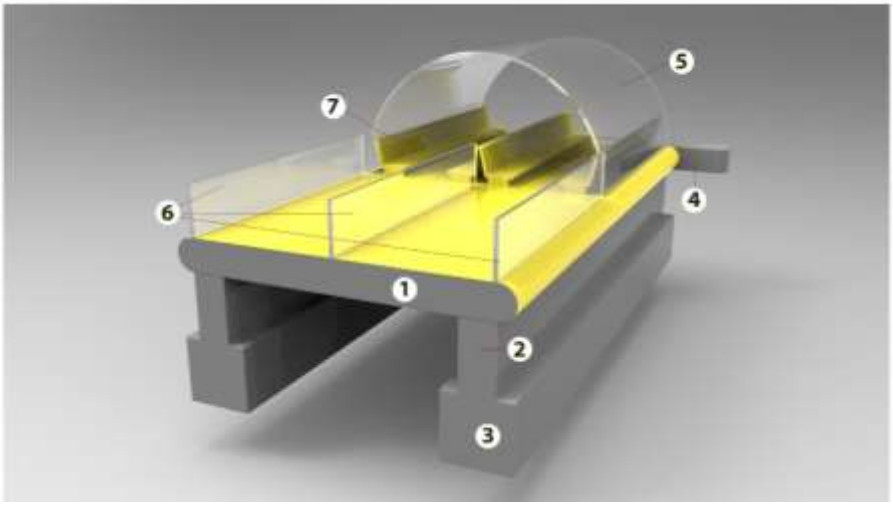
Material selected

The material selected: The Marine foam (Gurit® Corecell™ M)

- Gurit® Corecell™ M is one of the most recently and widely used in the Marine constructions and applications of marine
- The extra ordinary strength properties of the material enable the marine industry to widely use this material
- It also offers very high resistance to the temperature
- It provides a high shear strength with low density, high elongation, high-temperature resistance, and low resin uptake
- Gurit® Corecell™ M is also used for onshore construction of marine such as superstructure, deck etc
- However, the material possesses very low density when compared to other polymers
- Its high elongation property delivers higher useful and the toughness to give impact resistance and superior fatigue performance

Marine foam is one of the widely used material in marine constructions mainly yachts, ships, trimarans, etc. The test results were collected from the Gurit® Corecell official website on request.

Detailed design



Detailed figure of the Final concept

The above figure shows the final concept with the following labels:

1. Main slab (2m x 12m x 0.4m)
2. Web (0.4m x 12m x 0.8m)
3. Flange (0.8m x 12m x 0.8m)
4. Cantilever (which moves up and down freely on the basis of WL)
5. Roofing
6. Handrails (0.9m x 9m)
7. Seating

A mock-up model with a scale of 1:40 was made and tested in order to check the functionality and the performance of the final concept.

Conclusion

In general, the jetties are of lighter construction than general cargo-handling docks as they usually do not require warehouse or extensive cargo-handling equipment like large crane used to load and unload containers. The problem statement was that people found it difficult to board and de-board the boat to the jetty when there is a difference in water-level in rivers. Using boat services during the extreme summer season and the rainy season was reported as unsafe. Accidents are found during entering and leaving the jetty due to change in WLs in rivers. There is no design intervention done so far in the structure of the Marine Jetty. A Design Intervention for Jetty was done to improve the passenger comfort thereby making it more efficient when there is a change in WL by implementing the design. The design adopted was a floating structure, whose one end is fixed or cantilevered to the land in which a rotatory movement is possible. The other end is projected to the water which is freely moved in a vertical direction based on the change in WL. This reduces the risk of people boarding and

de-boarding the boat when there is a decrease or increase in water and thereby increasing the comfort and reducing the possibility of accidents.

Limitation

- The material used for the structure is a polymer. As we know plastic is a non-biodegradable substance and hence, they are not eco-friendly
- The selected design is a floating platform which is hinged at one end. The structure not static and the bases are not fixed, as a result, there will be slight movement based on the tides. However, the structure won't topple or go out of control (refer to appendix). There might be a stereotyping effect here to the passengers as they had been using a fixed platform

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Appendix

Design and Analysis of Main Jetty slab

No. of slab = 1
Span = 12 m
Thickness of slab = 450 mm (assume)
F_{ck} = 40 $^{N}/_{m^2}$
F_y = 500 $^{N}/_{m^2}$
Density of Concrete = 25 $^{kN}/_{m^3}$
Cover = 50 mm
Diameter of bar = 25 mm (assume)

Depth calculation for Serviceability requirements

Assume D = 450 mm
Depth provided, d_{pro} = 450-50-12.5 = 0.388 m
Depth required, d_{req}= $\frac{length}{a\ x\ r_d}$
Where a is the modification factor and r_d is the vertical deflection
According to f_s = 240 $^{N}/_{mm^2}$, P_t= 0.2%
As per IS 456-2000, pn-38, a = 1.6 and fig-4, r_d= 20
∴ Substituting the values, we get d_{req}= 0.375 mm
Where D is the nominal diameter of bar
d_{pro} The stress in the bar
d_{req}= $\frac{length}{a\ x\ r_d}$ is the design bond stress according to 26.2.1, IS 45:2000 (here 1.9)
Therefore L_d = 0.750 m
L_d Is the amount of reinforcement length needed to be projected into the pile to establish the desired bond strength between concrete and steel.

Load calculations in slab

Live load = 10 $^{kN}/_{m^2}$ (humans)
Volume of slab = 0.25 m x L x B = 0.25 x 12 x 2
= 6 m^3
Dead load = Vol x Unit weight = 6 x 25
= 150 kN
Live load = 10 x B x thickness = 10 x 2 x 0.25
= 5 kN
∴ Total load = DL + LL = 155 kN
Safety factor = 155 x 1.5 = 232.5 kN
Depth provided, d_{pro} = 0.388 m, d_{pro} > d_{req}
∴ Depth provided is enough
Provide 12 mm diameter bars @ 300 $^{mm}/_{cc}$ as distribution steel

Check for shear

V_u = 1.2 x Wu x L (b/ ()) = 265.9 kN

Ast_{pro} = 3272.49 mm^2

Pt_{pro} = 0.84

Pile design

Diameter of the pile (D) = 450 mm (assume)

Effective length of pile (Le) = 12 m (assume)

Le is the pile length which effectively transfers the load from the pile into the soil

Slenderness ratio (r) = $\frac{Le}{D} = \frac{12}{0.450}$ = 26.67

If slenderness ratio > 12, hence design as a slender column

Minimum eccentricity, $ex_{min} = \frac{I}{Fy} + \frac{D}{Le}$

I = $\frac{\pi d^4}{64}$ = 2.012 x 10^{-3}

Substituting the values for I, Fy, D, Le in ex_{min}, value for ex_{min} = 100 m (approx.)

Moment due to eccentricity

(Comparison between external moments and moments due to eccentricity)

Mux = Pu x e_{min}

Where Pu is the maximum vertical load (232.5 kN)

∴ Mux = 232.5 x 100 x 0.001 = 23.25 kNm

= 25 kNm (approx)

Additional moments

Clause 39.7.1 IS 456:2000

Max = $\frac{Pu \times D}{2000}$ x $[\frac{lex}{D}]^2$

May = $\frac{Pu \times D}{2000}$ x $[\frac{ley}{D}]^2$

Substituting the values for Max and May, we get

Max = 92.5 kNm

May = 92.5 kNm

∴ Total factored moments: Mux = Mux + Max

= 25 + 92.5

= 117.5 kNm

Muy = Muy + May

= 3 + 92.5

= 95.5 kNm

∴ Mu = 1.15$\sqrt{(Mux^2 + Muy^2)}$

= 1.15$\sqrt{(117.5^2 + 95.5^2)}$

= 174.12 kNm

~ 180 kNm

Design of Reinforcement

Grade of concrete, f_{ck} = 40 MPa

Grade of steel, f_y= 500 MPa

Assume diameter of bar = 32 mm

Assume cover of reinforcement = 75 mm
Total cover, d ' = 75 + (32/2) = 91 mm
d '/D = 91/450 = 0.2

$\frac{\text{Pu}}{\text{fck D}^2} = \frac{232.5 \text{ x } 10^3}{40 \text{ x } 450^2}$ = 0.028
$\frac{\text{Mu}}{\text{fck D}^3} = \frac{180 \text{ x } 10^6}{40 \text{ x } 450^3}$ = 0.04

From chart 60 of SP16, if P/fck = 0.04, then Preq = 0.04 x 40 =1.6%

∴ Ast required = $\frac{1.6 \text{ x } \pi \text{ d}^2}{4 \text{ x } 100} = \frac{1.6 \text{ x } \pi \text{ } 450^2}{4 \text{ x } 100}$ = 2545 mm^2
Area of a bar = $\frac{\pi \text{ d}^2}{4} = \frac{\pi \text{ x } 32^2}{4}$ = 803.84 mm^2
∴ No. of bars required = 2545 / 803.84 = 14

As per IS 456:2000, Clause 26.3.2;
Horizontal distance between 2 parallel main reinforcing bars shall not be less than diameter of the bar.

Here, diameter of bar is assumed as 32 mm
∴ Minimum spacing should not exceed 32 mm.

Required spacing = 142.07 mm
Maximum spacing = 300 mm

∴ Provide 32 mm diameter bar @ 100mm c/c.
∴ No. of bars required = 14

A_{st} provided = $\frac{30 \text{ x } \pi \text{ x } 450^2}{4}$ = 159043.12 mm^2
∴ A_{st} provided > A_{st} required

<u>Check safety under Biaxial Bending</u>

$\frac{\text{Pu}}{\text{fck D}^2}$ = 0.028
$\frac{\text{Mu}}{\text{fck D}^3}$ = 0.04 …. from chart SP 16, $\frac{\text{P}}{\text{fck}}$ = 0.04

$\frac{\text{Max}}{\text{fck D}^3} = \frac{92.5}{40 \text{ x } 450^3} = 2.5 \text{ x } 10^{-5}$
$\frac{\text{May}}{\text{fck D}^3} = \frac{92.5}{40 \text{ x } 450^3} = 2.5 \text{ x } 10^{-5}$

Puz = (0.45 fck) Ag + (0.75 fy – 0.45 fck)Ast
Fck = 40
Fy = 500 N/mm^2
A_{st} = 2.544 x 10^{-3} m^2
A_g = $\frac{\pi \text{ x D}^2}{4} = \frac{\pi \text{ x } 0.450^2}{4}$ = 0.15896 m^2
Substituting the above values in P_{uz},
P_{uz} = 2.86128 + 0.908208 = 3769.488 kN

$$\frac{P_u}{P_{uz}} = \frac{232.5}{3769.488} > 0.2$$

Hence $\alpha_n = 1$

$$(\frac{Mux}{Mux_1})^{\alpha_n} + (\frac{Muy}{Muy_1})^{\alpha_1}$$

Mux = 117.5 kNm

Muy = 95.5 kNm

Mux_1 & Muy_1 = $\frac{Max}{Fck\ x\ D^3}$ x Fck x D^3 = 91125

$\therefore \frac{117.5}{91125} + \frac{95.5}{91125}$ = 2.337 x 10^{-3} <1

Hence safe

Design of spiral reinforcement

Clause 39.4, IS 456:2000

Assume maximum compressive strain in concrete in axial compression is taken as 0.002

The ratio of the volume of spiral reinforcement to the volume of the cone shall not be less than 0.36.

Here fy = 500 N/mm2

Design of Pile cap

Pile cap dimensions are as follows:

Width = 0.6 m

Length = 0.6 m

Thickness = 0.5 m

Pile diameter = 450 mm

Cover of reinforcement = 50 mm

Grade of Concrete = 40 $^{N}/_{mm^2}$

Grade of steel = 500

Diameter of the bar = 20 mm

Axial load on pile = 1000 kN

Load calculation

Self-weight of the pile cap = 0.6 x 0.6 x 0.5 x 25 = 4.5 kN

Total load = Self weight + Axial load = 1004.5 kN

Intensity of pressure = total load / (l x b) = 1004.5/(0.6 x 0.6) = 2790 $^{kN}/_{m^2}$

Load on pile muff = 2790 $^{kN}/_{m}$