SHORE PROTECTION OF ARULMIGU SUBRAMANIYA SWAMY TEMPLE AT TIRUCHENDUR, TAMIL NADU

For

HINDU RELIGIOUS AND CHARITABLE ENDOWMENTS DEPARTMENT (HR&CE)
GOVERNMENT OF TAMIL NADU

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PREFACE

TIRUCHENDUR ARULMIGU SUBRAMANIYA SWAMY TEMPLE has the history of 17th century. The temple complex on the eastern side corridor has been experiencing erosion since 1960. The waves are breaking close to compound wall particularly in June-July (southwest monsoon) and November- December (northeast monsoon). Seawall has been built by dumping stones in 1963 and it has been periodically repaired.

However, shore protection is being done sporadically by repairing the collapsed section with additional dumping of stones. Of late, the Ocean Engineering Department, IIT Madras has proposed a seawall section for 520 m long along the temple complex. All efforts are being made without any scientific approach nor with measured oceanographic information.

Being a Devote of Lord Murugar and as an Oceanographic Scientist in CSIR-National Institute of Oceanography, Goa for 22 years and as Managing Director of the internationally reputed Indomer Coastal Hydraulics (P) Ltd., Chennai for 23 years, I have prepared this report on long term solution for the prevention of erosion. Indomer has done many EIA clearances related oceanographic studies and prepared reports for Tiruchendur Murugar temple without any charges to HR & CE.

Indomer had deputed team of engineers in March- April, 2021 with imported oceanographic survey equipments to carry out large seabed surveys covering 12 km along the coast and 9 km into the sea at Tiruchendur. An exclusive mathematical modelling study had been carried out using DHI-MIKE 21 model, to understand the propagation of concentration of wave energy from deep water towards the shore.

The findings indicate that the natural calcareous/pearl/coral reefs existed during historical time at 1 km distance offshore were destroyed due to illegal mining and the damaged reef present now is not offering protection to the shore near temple complex from the waves. During monsoon periods, these damage reefs are not able to attenuate the high waves, which approach the shore, break on compound wall and cause erosion.

The present study identifies the reasons for erosion and recommends the reconstruction of damaged reef by placing artificial reefs consisting of concrete hollow shell blocks. It is an eco-friendly method, the hollow blocks will protect the shore, increase fish breeding and help coral/pearl growth. It has been proposed in two phases of construction and the areas for each phases are marked and presented in the report. The method of providing artificial reef as described in this report to reconstruct the lost reef has the promising way to prevent coastal erosion along the temple complex permanently.

Dr. P. Chandramohan
5, August 2021

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1. INTRODUCTION

Tiruchendur Arulmigu Subramaniya Swamy Temple is an ancient Hindu temple has the history of 17th century and reckoned as the second largest pilgrimage in Tamil Nadu, India. It is proclaimed as one of the six Great Abodes (in Tamil Arupadai Veedu) of Lord Murugan, the Tamil God. Among the six abodes, the Tiruchendur temple, the second abode, carries the fame of its uniqueness situated on the shore, facing the Gulf of Mannar, whereas all other five abodes are located on hillocks inland. The Temple possesses legendary all over the world and for the millions of devotees from India, Sri Lanka, Australia, Canada, United States, Malaysia, Singapore, United Kingdom, Mauritius, and Reunion Island etc. More than ten million devotees keep visiting the temple to celebrate various festivals throughout the year. The largest gathering is for the Kanda Sasti festival celebrated for six days, on the last day one million people gather to witness the God killing the evil Surapadma at seashore. The beach erosion over the last 60 years had so advanced and presently the eastern side of the temple complex fall close to the high tide line.

A seawall was first built in 1963 to protect the temple structures. The seawall was either periodically repaired or rebuilt but without any scientific approach leading to a consistent problem and threat to the temple stability. At present, there is a large-scale damage to the seawall and the wave run up rise into main temple corridor on spring tidal days and on northeast monsoon days.

This report describes the detailed scientific study undertaken on ocean climate, modeling study on wave concentration, the influence of littoral drift and the cause for the erosion. Also, a long-term eco-friendly engineering solution has been suggested for preventing further erosion. Indomer had carried out the necessary oceanographic studies in April 2021.

This report presents the methodology and results of the surveys. The location map is shown in **Fig. 1.1.**

All calendar dates are referred in Indian style as dd.mm.yy. (eg. 11.07.21 for 11th July 2021) and the time is referred to Indian Standard Time in 24-hour clock, eg. 3 P.M. is written as 1500 hrs. SI units are followed for fundamental and derived units. The depths are referred with respect to Chart Datum. The UTM coordinates are indicated in WGS 84 spheroid - Zone 44N.

2. HISTORY OF TEMPLE

The temple was built on the seashore in 17th century. The temple complex measures 91 m north to south and 65 m east to west. It has a 42 m high seven tier tower (Kopuram). The principal entrance from south is elevated but the inner corridor where main deity stands remains below sea level. Devotees undergo a ritual cleansing by bathing in the sea. Later, the Murugar temple at Tiruchendur was occupied by the Dutch East India company from 1646 to 1648, during the course of their war with the Portuguese.

The Dutch army finally vacated the temple on orders from the Local Tamil King. However, while leaving, they removed the holy idols of Lord Murugar made of an alloy and carried with them. Immediately on setting sail, they encountered a very heavy storm and realized their mistake of stealing the idol. They dropped the idol immediately in the sea and noticed the storm too stopped immediately. Later, Lord Murugar appeared in a dream of a devotee and revealed the place he was lying beneath the sea. The devotee then retrieved the idol in 1653 and reinstated in the temple. The temple was given total face lifting in 1941.

2.1. Morphology

Tiruchendur temple is located in the coast of Gulf of Mannar. This stretch has two varying morphological formation, one between Kanyakumari and Manapad; and another Manapad to Tuticorin. The remnants of Kondalite rocks are present at offshore between Kanyakumari and Manapad. The stretch between Manapad and Tuticorin is very prominent for the formation of offshore reefs and Pearl Banks. The historical Indian Naval Hydrographic Chart (No.262) is shown

in **Fig. 2.1.** These reefs along the Manapad and Tuticorin are formed by calciferous sand stones. They act like a submerged breakwater protecting the coastline from the impact of waves. Manapad Point is a high sandy promontory with a rock substratum. There is a long barrier beach extending from the Manapad Point connecting a shallow offshore reef.

The coast between Manapad Point and Tuticorin is very low present with sandy beaches. Alanthalai offshore shoal is very prominent. Tiruchendur headland remains as low rocky headland and from there series of very shallow offshore reefs are noticed till Punnaikkayal. There is a large tidal swamp around Punnaikkayal with presence of mangroves where the distributaries of Thambraparani river join the sea. Large spread of salt pans is present around Tuticorin. The sandy beaches are extensively developed at many places along the coast between Kanyakumari and Tuticorin. Well-developed beaches are seen at Idinthakarai, Koodankulam, Perumanal, Uvari, Manapad, Kulasekarapatnam and Kayalpatnam.

The coastal sector between Tiruchendur and Tuticorin is with sandy beach with sporadic rocky outcrops. There are shallow reefs present offshore which protect the shore from the monsoon waves. The coastal sector between Tiruchendur and Manapad consists of rocky platform and cliffed reef with calcareous sandstone. The cliff sections at Manapad and Tiruchendur are acting as headlands and diffract the incident waves. In these cliffed sections the stages of wave cutting cave formation are located at 1.5 m and 3 m above Mean Sea Level (MSL). The Manapad and Tiruchendur headlands are the sedimentary type calcareous sand stones offer protection against wave action.

2.2. Oceanography

The oceanographic process of Tiruchendur sea is dominated by three seasons: i) southwest monsoon (June to September), ii) northeast monsoon (October to January) and fair-weather period (February to May).

Gulf of Mannar is partially protected from monsoon waves by Sri Lanka Island. The beach formation vanishes on the southern peninsular tip and is replaced by rocky shores. Thambraparani, Vembar and Vaipar are the important rivers joining the sea in this region. Formation of sandy islands off Tuticorin and large storage of beach sand between Manapad and Tiruchendur indicates the movement and depositional features of the littoral drift. Numerous shoals are noticed off Manapad within 20 m depth contour. The shoreline between Tiruchendur and Kanyakumari is exposed with beach rocks. Submerged barrier reefs are noticed in the nearshore causing the waves to break offshore. Abundant wealth of corals, oysters, sponges and other sea water animals flourish in Gulf of Mannar.

2.3. History of Erosion

Tamil Nadu is located on the southeast of Peninsular India. Its coastline starts from Pulicat Lake in the north extending up to Kanyakumari in the south bordering the Bay of Bengal. Major erosional and depositional landforms can be found along the southeastern coast of Tamil Nadu. Among the depositional landforms, prominent features are beach ridges, swales, spits, and estuaries. The major erosional landforms are wave cut platforms, cliffs, marine terraces, sea caves etc. which can be seen near Rameswaram, Mandapam, Valinokkam, Kannirajapuram, Tiruchendur, Manapad, Idinthakarai and Kanyakumari. The attention is more focused on the erosion at Tiruchendur Arulmigu Subramaniya Swamy. The eastern side of the temple complex has been subjected to severe erosion for the last 60 years. Presently, there is an extensive damage to the seawall and the breaking waves rise over the temple corridor particularly on monsoon days, causing a vulnerable threat for the existence of temple. The seawalls made of quarry stones were built in 1963 as seawall and repaired periodically. The concrete cubes were dumped along the eroded part of the shore in 2018. The shore protection efforts are being carried out in haphazard manner without any scientific approach. It has led the erosion to remain till date and cause threat to the temple complex. The present study attempts to identify the cause of erosion and most suitable method for a long term solution.

Southern view of Beach

Northern view of Beach

3. OCEANOGRAPHIC SURVEY

3.1. Tides

The variation of design tide levels with respect to Chart Datum for Tuticorin presented in Naval Hydrographic Chart No. 262 published by Surveyor General of India is given in **Table 3.1.** These tides are applicable for Tiruchendur.

Table 3.1. Design of tide levels

Tide	Level (m)
Mean High Water Spring (MHWS)	+ 1.0
Mean High Water Neap (MHWN)	+ 0.7
Mean Sea Level (MSL)	*+ 0.6*
Mean Low Water Neap (MLWN)	+ 0.5
Mean Low Water Spring (MLWS)	+ 0.3

The tidal levels during the period of 25.04.21 to 02.05.21 was reduced to chart datum and is shown in **Fig. 3.1.** The spring tidal range existed around 0.9 m and the neap tidal range existed around 0.5 m.

3.2. Currents

The current measurement was carried out for 7 days at 2 km off project location. The variation of current speed & direction with polar plot is shown in **Fig.3.2.**

The maximum current speed observed in the measured location is around 0.16 m/s. The current direction varied around 360°. The data on currents show that in general, the currents are moderate and are influenced mostly by wind followed by tides.

3.3. Waves

Based on the available Indomer - in house wave data over the period of one year. The predominant monthly characteristics are given in **Table 3.2.** The monthly and annual wave roses are shown in **Fig. 3.3.**

Table 3.2. Predominant wave characteristics

Month	Monsoon	Significant wave height (m)	Zero crossing wave period (s)	Predominant wave direction (°N)
February	Fair weather	0.5-1.0	4-5	135.0 -180.0
March		0.5-1.0	4-5	135.0 -180.0
April		0.5-1.0	4-5	135.0 -157.5
May		0.5-1.5	4-5	135.0 -180.0
June	SW monsoon	0.5-1.5	5-6	135.0 -157.5
July		0.5-1.5	4-6	135.0 -157.5
August		0.5-1.5	5-6	135.0 -157.5
September		0.5-1.5	5-6	135.0 -157.5
October	NE monsoon	0.5-1.0	4-6	135.0 -180.0
November		0.5-1.0	4-5	135.0 -180.0
December		0.5-1.0	3-5	135.0 -180.0
January		0.5-1.0	3-5	135.0 -157.5

3.4. Littoral drift

Using the following CERC equation and the measured wave data of one year, the littoral drift near the Tiruchendur shoreline has been estimated and presented in **Table 3.3.** *(Coastal Engineering Manual, EM1110 -2-1100 (Part III), 30 April 2002, U.S. Army Corporation of engineers (USACE)).*

$$Q_l = K\left(\frac{\rho\sqrt{g}}{16k^{\frac{1}{2}}(\rho_s - \rho)\,(1-n)}\right)H_b^{\frac{5}{2}}\sin(2\alpha_b)$$

Where,

- Q_l - Volume transport rate, m^3/s
- H_b - Breaking wave height
- K - 0.92 [if $H_b = H_{rms}$] or 0.39 [if $H_b = Hs$]
- κ - 0.78
- ρ_s - Density of sediment = 2650 kg/m^3
- ρ - Density of seawater = 1025 kg/m^3
- n - Sediment porosity = 0.4
- α_b - Breaker angle with respect to shoreline
- g - Acceleration due to gravity = 9.81 m/s^2

Table 3.3. Littoral drift along Tiruchendur coast

Month	Quantity (m^3/month)	
	Northerly	Southerly
January	-9985	6419
February	-12361	5371
March	-18542	6265
April	-24807	0
May	-38197	319
June	-35035	804
July	-27974	0
August	-32758	105
September	-38489	121
October	-30898	205
November	-21239	411
December	-7575	6796
Annual Gross (m^3/year)	0.33×10^6	
Annual Net (m^3/year)	-0.22×10^6 (Northerly)	

The total annual gross transport is as found to be 0.33×10^6 m^3/year and the annual net transport is 0.27×10^6 m^3/year towards north. It is of very low order compared to the rest of East coast of India on the northern side of Tamil Nadu coastline wherein the gross transport reaches 1×10^6 m^3 per year *(Jena et al.,2000)*

4. BATHYMETRY SURVEY

4.1. Methodology

Reference spheroid

World Geodetic System (WGS84) spheroid – Zone 44 was followed for entire surveys and for the presentation in the report.

Horizontal control

Reference station: The DGPS Beacon Transmitter installed by Department of Lighthouse and Navigation at "*Pandiyan Thivu" by department of light house and navigation*" was taken as reference station. The transmitting frequency of this reference station DGPS Beacon transmitter is 309 kHz.

Mobile station: The horizontal positioning of the mobile unit was carried out using Hemisphere R100 Series DGPS Beacon Receiver. It combines high-performance GPS reception with a DGPS-capable receiver in a lightweight, durable housing and comes with a separate antenna. It gives the horizontal position to an accuracy of close to 1 m.

The GPS receiver also contains technology enabling *WAAS/EGNOS*, *Omni STAR* or *Beacon* real time differential capabilities. When used with a Real- time Kinematic (RTK) Base station, the GPS receiver provides RTK positioning for high-accuracy, centimeter-level applications. A standard GPS receiver provides the following features:

- 10 Hz (10 positions per second) output rate
- 12 GPS (C/A-code L1, C/A code L2 (for the Omni STAR XP/HP and RTK models) tracking channels, code carrier channels
- Sub meter differential accuracy (RMS), assuming at least five satellites and a PDOP (Position Dilution of Precision) of less than four (when used with Satellite Based Augmentation Systems (SBAS) correction).

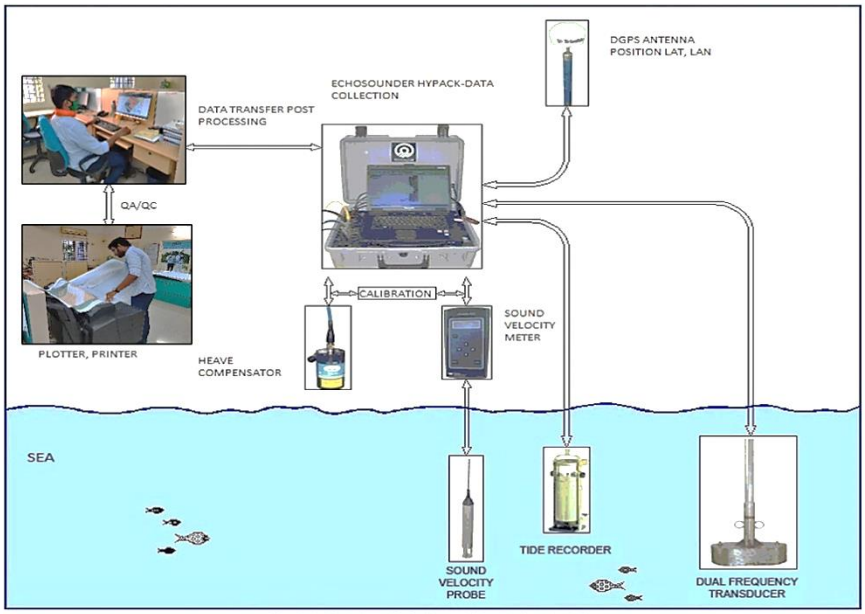
The system configuration is enabled with

- LED display and keypad
- Outputs a 1 PPS (pulse per second) strobe signal on both ports. This signal enables an external instrument to synchronize its internal time with a time derived from the very accurate GPS system time.
- SBAS such as WAAS (Wide Area Augmentation System) differential correction 1
- Beacon differential correction
- Omni STAR VBS capability

- Omni STAR XP/HP capability in the XP/HP and RTK models
- RTK positioning capability, In the RTK model only
- EVEREST™ multipath rejection technology
- Two connectors that support both CAN 2.0B and RS-232:
- CAN: J1939 and NMEA 2000 messages, RS 232
- NMEA-0183 output: GGA, GLL, GRS, GST, GSA, GSV, MSS, RMC, VTG, ZDA (the default NMEA messages are GGA, GSA, VTG, and RMC).

Area of survey: Extensive bathymetry survey was carried out covering an area of 12 km distance along the coast and 9 km distance into the sea at 50 m line spacing. The transect lines were planned perpendicular to the coast.

Instrument arrangement: The configuration of various arrangements for conducting the bathymetry survey is shown below.



CONFIGURATION OF BATHYMETRY FLOW CHART

The survey vessel ***'KANNAMMA'*** was used for the survey. The Echosounder transducer was mounted on the star board side of the vessel by positioning it at 0.5 m below the sea surface. The DGPS receiver antenna was mounted on the mast vertically in line with the transducer, so that it represents the exact coordinates of the location where the depth is simultaneously measured by the transducer.

The Heave Sensor was attached close to transducer stem on the boat deck to measure the residual vertical displacement of the boat induced by external disturbances and to carry out the correction.

The DIGIBAR-PRO sound velocity meter was used to measure the sound velocity across the vertical and entered as input for calibrating the transmitting part of the instrument. The bar check was also carried out by lowering the rigid plate at different depths and comparing with the displayed depth. The necessary inputs were given in HYPACK data collection software before the commencement of the survey. The planned track lines were displayed on the monitor at wheel for navigation. Watch guards were positioned at bow, transducer/antenna, heave compensator and at rear end.

The data were continuously collected at onboard PC along each transect. After that day data collection was made, entire data were downloaded to external hard disc and stored. The recorded data includes: date, time, latitude, longitude, X coordinate, Y coordinate and heave. The depth data was recorded at 0.2 sec interval. A tide recorder was deployed using a bed mounting frame and data were recorded separately in the internal memory.

The collected data were processed in the laboratory with corrections on tidal variation and transducer draft.

ODOM Echotrac CVM Digital Dual Frequency Echo sounder manufactured by ODOM Hydrographic Systems; USA was used for the survey. This echo sounder has incorporated the cutting-edge technology, features and reliability of the Echotrac MKIII, plus the ease and flexibility of operation of a networked Windows interface. It operates in dual frequency consisting of 200 kHz on higher band and 33 kHz in lower band. It can be operated from 0.2 m to 1500 m water depth with 0.01 m accuracy. The Echotrac CVM transceiver units are compact rack mount package that is ideally suited to survey vessel installations.

It supports Chart-functionality in one optional format and a laptop with a full-size color LCD as an "electronic chart". The optional color LCD laptop offers internal data storage (in. XTF format) and playback of the analog return signal digitized to full 16-bit resolution. It contains a dual channel board. All channels feature a robust design and frequency agility enabling the operator to precisely match the transceiver to almost any existing transducer. Operator selectable TVG curves serve to optimize the Echotrac for both shallow and deep-water bottom detection tasks and for Sonar imaging.

The Echotrac CVM features unsurpassed interfacing flexibility, offering 2 serial ports that can be configured to interface with computers and motion reference units. It has an Ethernet port that outputs the 16-bit samples of the acoustic data for further processing and supports a number of output formats that are compatible with most common Echo Sounder strings.

Technical specifications

Frequency	:	High Band: 200 kHz Low Band: 33 kHz
Input Power	:	110 or 220 V AC or 24 VDC 50 watts
Resolution	:	0.01 m / 0.1 ft.
Accuracy	:	m / 0.10 ft. +/-0.1% of depth @ 200 kHz 0.01 m / 0.30 ft. +/- 0.1% of depth @ 33 kHz
Depth range	:	0.2 – 200 m / 0.5 – 600 ft. @ 200 kHz 0.5 – 1500 m / 1.5 – 4500 ft. @ 33 kHz
Sound Velocity	:	1370 – 1700 m/s
Resolution	:	1 m/s
Depth Display	:	On control PC
Clock	:	Internal battery backed time, elapsed time, and date clock
Annotation	:	Internal – date, time, GPS position External – from RS232 Port or Ethernet
Interfaces	:	2 x RS232 serial ports, baud rate selectable 4800-19200. Input from external computer, motion sensor, and sound velocity. Outputs to external computer. Ethernet interface. Heave – TSS1 and sounder sentence
Blanking	:	0 to full scale
Software	:	Echotrac Control supplied. Chart View display and logging software.

Hydrographic Survey Software: HYPACK 2021 survey software was used for data collection and processing. It is integrated, first generation hydrographic survey software developed by Coastal Oceanographical INC., USA. It works in MS Windows operating environment. The HYPACK's design program allows to import background map in CAD's DFX or Microsoft's DGN format. It enables to quickly create planned survey lines, plotting sheets and bottom coverage grids in a graphical environment. It gives the flexibility to support multiple navigational systems (GPS, range/range, range/azimuth), echo sounders (signal and dual frequency, multiple transducers and multibeam), magnetometers, ROV-tracking systems, telemetry tide systems and many other devices. It contains the post processing module to analyze and prepare the chart. The survey tracks were planned using this software for accurate maneuvering of the vessel and to keep the accuracy of the track. The post processing of the survey data and preparation of map were carried out using this software.

Heave Compensator: TSS HS-50 Dynamic Motion Heave Sensor manufactured by TSS (UK) Ltd.; UK was installed onboard. It was measured the component of the heave induced at echo sounder transducer. The measured heave was corrected from the depth values and the true depth was recorded in computer. The system was connected via. RS232 communication to the computer onboard enabled through HYPACK data collection software.

Data recording: The Echosounder, heave compensator and Beacon DGPS receiver were interfaced through HYPACK software with onboard PC. The entire system was supported by AC Power Generator installed onboard. The position and depth were recorded along the pre-planned transect at 200 millisecond intervals continuously.

Calibration: Calibration for Sound Velocity: ODOM DIGIPRO SVM has been used to measure the velocity of sound across the vertical and the mean value was fed in the echo sounder during calibration before the commencement of survey on each day. The sound velocity correction was also logged and fed to the software at every two hours during the survey. Calibration by Bar Check: Bar check was performed before starting and after completion of the survey on every day. It was done by lowering a bar plate at known depth below the transducer. The correction coefficients for known depth were noted and entered on the data collection software.

Tidal correction: The necessary tidal corrections were applied for the collected bathymetry data based on the measured tides at the site.

4.2. Results

The bathymetry charts are prepared in WGS84 spheroid with UTM (Zone 44) coordinates supplemented by Geographical coordinates indicating the latitude and longitude. The depths are presented with respect to Chart Datum (CD).

The bathymetry map covering 12 km x 9 km area is prepared in A3 size in 1:50000 scale is presented in **Fig. 4.1.**

The bathymetry chart prepared for the temple area covering 5.5 km x 3.2 km in in A3 size in 1:20000 scale is presented in **Fig. 4.2.**

In addition, the 3D map prepared separately to identify the existing reef and outcrop rocks is prepared in **Fig. 4.3.** The spectrum bathymetry map prepared A3 size shown in **Fig.4.4.**

Discussion: The orientation of the coastline takes a turn near the temple complex from 42°N on the southern side to 0°N on the northern side. The bathymetry is also noticed to change greatly, remains very shallow on the northern side and slightly steeper on the southern side. The contours are parallel on the southern side till 6 m water depth which occurs at distance of 1 km. The region between 7 m and 8 m water depth shows rise and fall depicting the undulations of calcareous floor. The northern side formed as a bay showing shallow till 6 m water depth occurring at 3.5 km offshore.

Shallow reefs are present at north of the temple complex with depth varying between 1 m and 3 m. Two elliptical shallow reefs of 900 m x 200 m and 150 m x 90 are noticed with a discontinuity (**Fig. 4.1).** The water depths over these reefs are 1 m to 2 m and there is a discontinuity of 1000 m gap between the two reefs. The waves are seen penetrating through this gap and reach the shoreline close to the temple. The 9 m and 10 m depth contours run almost parallel at 6 km offshore in SW-NE direction. Further offshore, the seafloor has a cusps like rise and fall with depth varying from 12 m to 16 m.

The presence of chain of 10 km long submerged reefs from Tiruchendur towards north which are identified as pearl banks in the past (Ref. **Fig.2.1.**) The deeper contour of 15 m occurs at 7 km offshore. The depth Vs distance inferred from bathymetry chart are given in **Table 4.1.**

Table 4.1. Depth Vs Distance

Depth w.r.t. CD (m)	Distance from shore (m)		
	Southern side (Alanthalai)	Opposite to Tiruchendur beach	Northern side (Virapandianpatnam)
1	160	70	30
2	300	340	65
3	500	840	650
4	760	930	1375
5	925	1150	4170
6	1075	1450	4220
7	1460	1660	4270
8	2020	3100	4400
9	3600	3300	6130
10	3770	3450	6250
11	4200	3670	6700
12	5600	4000	6860
13	5640	4530	7030
14	5950	4830	8460
15	6600	7200	9100

Installation of Transducer

Bathymetry survey

RTK Base station

Taking levels at wave breaking zone

5. REASON FOR EROSION

The reason on shoreline erosion at temple complex is mainly attributed due to the illegal mining on the corals and calcareous rocks which were prevent at 1000 m offshore from temple complex (Fig. 4.1). These regions are well known historically for the pearl culture during Pandya Dynasty in 14th century. Now region in Gulf of Mannar at 40 km north of Tiruchendur has been declared as Marine Park Reserve and the Coral reef. Those days the presence of coral reefs, atolls, shallow calcareous reef acted as a barrier to save the temple from strong waves and currents. The removal of these resources has made the shoreline for vulnerable erosion.

The calcareous reef of 400 m long and 150 m wide at 1000 m offshore opposite to temple complex had been damaged and removed in the past which allows high wave to pass through and attack the shore. The erosion is more pronounced during southwest monsoon (June to September) and northeast monsoon (October to January) whenever the incoming waves are more than 1.5 m.

The proposed method of placing artificial reef over the destructed area can be a more suitable and permanent solution to protect the temple shoreline on longterm basis than constructing seawall and repairing very frequently.

Interventions like coral reef rehabilitation would help to reduce the impact of strong waves. The artificial reefs outside the Marine National Park will help to enhance the fish breeding areas. The artificial reef modules/blocks are effective methods for enhancing and protecting shoreline, natural resources as well as improving fisheries and aquaculture opportunities.

The reason for erosion such higher wave concentration through the damaged reef are Explained in Chapter 6

6. MATHEMATICAL MODELLING STUDY ON WAVE CONCENTRATION – MIKE 21 SW MODEL

The wave transformation was carried out using MIKE 21 SW model to understand the modified wave fields at nearshore particularly close to the existing and proposed reef area.

Spectral Wave Model: The MIKE 21 SW module includes two different formulations: i) Directional decoupled parametric formulation and ii) Fully spectral formulation. The directional decoupled parametric formulation is based on a parameterization of the wave action conservation equation. The parameterization is made in the frequency domain by introducing the zeroth and the first moment of the wave action spectrum as dependent variables. The basic conservation equations are formulated in either Cartesian co-ordinates for small-scale applications or polar spherical co-ordinates for large-scale applications.

MIKE 21 SW includes the following physical phenomena:

- *Wave growth by action of wind*
- *Non-linear wave – wave interaction*
- *Dissipation due to white capping*
- *Dissipation due to bottom friction*
- *Dissipation due to depth – induced wave breaking*
- *Refraction and shoaling due to depth variations*
- *Wave-current interaction*
- *Effect of time-varying water depth and flooding and drying*

The discretization of the governing equation in geographical and spectral space is performed using cell-centered finite volume method. In the geographical domain, an unstructured mesh technique is used. The time integration is performed using a fractional step approach where a multi sequence explicit method is applied for the propagation of wave action. It is used for the assessment of wave climates in offshore and coastal areas both in hindcast and forecast mode. This model can also be used to calculate the radiation stresses, wave induced flow field and wave induced sediment transport.

6.1. Model description

The wave action density spectrum varies in time and space and is a function of two wave phase parameters. The two wave phase parameters can be the wave number vector k with magnitude, k, and direction, θ, and either the relative (intrinsic) angular frequency, $\omega = 2\pi f_r$, or the absolute angular frequency, $\omega = 2\pi f_a$. In the present model the formulation in terms of the wave direction, θ, and the relative angular frequency, ω, has been chosen. The action density, N(ω, θ), is related to the energy density E(ω, θ) by,

$$N = \frac{E}{\sigma}$$

For wave propagation over slowly varying depths and currents the relation between the relative angular frequency (as observed in a frame of reference moving with the current velocity) and the absolute angular frequency, ω, (as observed in a fixed frame) is given by the linear dispersion relation:

$$\sigma = \sqrt{gk\ tanh(kd)} = \omega - \vec{k}.\vec{U}$$

Where g is the acceleration of gravity, d is the water depth and U is the current velocity vector. The magnitude of the group velocity, Cg, of the wave energy relative to the current is given by

$$c_g = \frac{\partial\sigma}{\partial k} = \frac{1}{2}\left(1 + \frac{2kd}{sinh(2kd)}\right)\frac{\sigma}{k}$$

The phase velocity, C of the wave relative to the current is given by

$$c = \frac{\sigma}{k}$$

6.2. Wave action conservation Equations

The governing equation, i.e., the wave action balance equation formulated in Cartesian co-ordinates, is given by,

$$\frac{\partial N}{\partial t} + \Delta.(\vec{v}N) = \frac{S}{\sigma}$$

Where,

N (x, θ, t)	-	wave action density,
t	-	Time
x	-	(x, y) Cartesian co-ordinates
v	-	(cx, cy, cz) is the propagation velocity of a wave group in the four Dimensional phase space x, t and θ
S	-	Source term of the energy balance equation
Δ	-	Four-dimensional differential operator in the x, θ space.

The four characteristic propagation speeds are given by

$$(c_x, c_y) = \frac{dx}{dt} = c_g + \vec{U}$$

$$c_\sigma = \frac{d\sigma}{dt} = \frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t} + \vec{U}.\nabla_{\vec{x}}d\right] - c_g\vec{k}.\frac{\partial\vec{U}}{\partial s}$$

$$c_\theta = \frac{d\theta}{dt} = \frac{1}{k}\left[\frac{\partial\sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k}.\frac{\partial \vec{U}}{\partial m}\right]$$

Where,

s - Space-co-ordinate in wave direction θ,
θ - Wave direction (deg. North)
m - Co-ordinate perpendicular to s.
$\nabla_{\vec{x}}$ - Two- dimensional differential operator in the $\vec{x}$ – space.

Grid schematization - Flexible Mesh

To ensure a good representation of wave transformation, the study area is digitized using flexible mesh (finite element triangular mesh). A triangular mesh system with relatively finer spacing that is 30 m in study region has been generated. It covers an area of 12 km x 10 km. The generated system of flexible mesh comprised of approximately 88,840 nodal points.

6.3. Model input

Bathymetry: Water depths were extracted from measured data and surveyed by Indomer.

Incoming waves: The analysis of 1 year measured wave statistics define the wave condition at the proposed study area and accordingly offshore wave height of 2 m, wave direction - 90° N, 135° N and 180° N and wave period of 8 s have been selected and used as the input to the MIKE 21 - SW model.

90° Wave Attenuation – Worst scenario for NE monsoon

The distribution of wave concentration at present, after Phase I construction of artificial reef and after Phase II construction of artificial reef in case of the waves coming from 90° are shown in **Fig. 6.1 and Table 6.1.**

Present situation: With the predominant direction of waves from east, the simulation shows that for present construction, the incoming wave height of 2 m, the attenuated waves after passing the existing shallow reef is the order of 1.0 to 1.1 m showing 50% attenuation.

After phase-I reef construction: The wave transformation study shows that for the direction of waves coming from east, the simulation shows that after Phase I reef construction over the limited area, for the incoming wave height of 2 m, the attenuated waves after passing the built up artificial reef will be the order of 0.5 – 0.6 m showing 75% attenuation.

After phase-II reef construction: The wave transformation study shows that for the direction of waves coming from east, the simulation shows that after Phase II reef construction over the larger area, for the incoming wave height of 2 m, the attenuated waves after passing the built up artificial reef will be the order of0.1 to 0.2 m showing more than 90% attenuation.

135° Wave Attenuation - Worst scenario for SW monsoon

The distribution of wave concentration at present, after Phase I construction of artificial reef and after Phase II construction of artificial reef in case of the waves coming from 135° are shown in **Fig. 6.2 and Table 6.1.**

Present situation: With the predominant direction of waves from 135°, the simulation shows that for present construction, the incoming wave height of 2 m, the attenuated waves after passing the existing shallow reef is the order of 1.0 to 1.1 m showing 50% attenuation.

After phase-I reef construction: The wave transformation study shows that for the direction of waves coming from 135°, the simulation shows that after Phase I reef construction over the limited area, for the incoming wave height of 2 m , the attenuated waves after passing the built up artificial reef will be the order of 0.4 - 0.5 m showing 75% attenuation.

After phase-II reef construction: The wave transformation study shows that for the direction of waves coming from 135°, the simulation shows that after Phase II reef construction over the larger area, for the incoming wave height of 2 m, the attenuated waves after passing the built up artificial reef will be the order of 0.1 - 0.2 m showing more than 90% attenuation.

180° Wave Attenuation - Worst scenario for cyclone

The distribution of wave concentration at present, after Phase I construction of artificial reef and after Phase II construction of artificial reef in case of the waves coming from 180° are shown in **Fig. 6.3 and Table 6.1.**

Present situation: With the predominant direction of waves from 180°, the simulation shows that for present construction, the incoming wave height of 2 m, the attenuated waves after passing the existing shallow reef is the order of 0.9 - 1.0 m showing 50% attenuation.

After phase-I reef construction: The wave transformation study shows that for the direction of waves coming from 180°, the simulation shows that after Phase I reef construction over the limited area, for the incoming wave height of 2 m , the attenuated waves after passing the built up artificial reef will be the order of 0.4 - 0.5 m showing 75% attenuation.

After phase-II reef construction: The wave transformation study shows that for the direction of waves coming from 180°, the simulation shows that after Phase II reef construction over the larger area, for the incoming wave height of 2 m, the attenuated waves after passing the built up artificial reef will be the order of 0.1 - 0.2 m showing more than 90% attenuation.

Table 6.1. Attenuated wave parameters near temple complex

Scenarios	Design wave height (m)	Wave period (S)	Design wave direction (°N)	Breaking wave height near Temple complex (m)
Present seafloor	2 m	8	90	**1.0 – 1.1**
			135	**1.0 – 1.1**
			180	**0.9 – 1.0**
Case II After Phase I construction	2 m	8	90	**0.5 – 0.6**
			135	**0.4 – 0.5**
			180	**0.4 – 0.5**
Case III After Phase II construction	2 m	8	90	**0.1 – 0.2**
			135	**0.1 – 0.2**
			180	**0.1 – 0.2**

The wave coming from east during Northeast monsoon (October to January) cause more concentration of wave energy on temple complex followed by the waves criteria and waves coming southeast direction during southwest monsoon (June to September). The model studies indicate that the present reef system provides 50% attenuation and whenever the deep-sea waves are more than 2 m, it poses risk and cause severe erosion near the temple complex.

If the artificial reefs are placed over the area as indicated for phase I construction, it would provide good shelter by reducing the wave height to 25 % of those waves approaching from the offshore. It implies if the incoming waves are 2 m higher, then it will reduce to 0.5 m while breaking near temple complex

If the artificial reefs are placed over the area as indicated for phase II construction, it would provide adequate shelter by reducing the wave height 10 % of those waves approaching from the offshore. It implies if the incoming waves are 2 m higher, then it will reduce to 0.2 m while breaking near temple complex

It is inferred that such reduction in wave height would offer full protection to the shore forever.

7. CONSTRUCTION ARTIFICIAL REEF

There are many field trials and implementation of using artificial reefs acting as submerged breakwaters contributing to shore protection and stabilization of beaches; and thereupon improving the biological lives in the sea. Submerged breakwaters help with stabilization of eroding beaches while minimizing the adverse impacts on adjacent beaches. The wave attenuation is the main mechanism by which submerged artificial reefs assist with stabilization of shorelines. The wave attenuation is quantified by the wave transmission coefficient, which is the ratio of the transmitted wave height to the incident wave height. Due to the complexities in wave breaking, physical and numerical model tests are performed to determine the wave transmission coefficients for various structural configurations. (*Armono et al.,2004*)

On placement of submerged artificial reefs, the wave attenuation generally increases with wave height. During period of smaller waves, little or no wave attenuation occurs, with the waves passing unaffected over the submerged structure. The stability of the reef due to waves and currents should be considered in the design aspect. An artificial reef concrete blocks are submerged or partly exposed to tides, the structure deliberately placed on the seabed to follower some functions of a natural reef, such as protecting, regenerating, concentrating or enhancing populations of living marine resources.

This includes the protection and regeneration of habitats. Also, it will serve as habitat that functions as part of the natural ecosystem. This allows the normal coastal processes to occur in the lee of the reef without disruption, thereby minimizing any adverse effects on adjacent beaches. During period of larger waves, the reefs enforce the waves to break, reducing the wave energy reaching the shore, thereby reducing the erosion. (*Harris et al.,2009*).

The proposed method of placing artificial reef over the destructed area can be more suitable and permanent solution to protect the temple shoreline on a long-term basis instead of constructing seawall which must be maintained very often. Interventions like coral reef rehabilitation would help to reduce the impact of strong waves and Artificial reefs outside the Marine National Park boarding in the seaward side would help to reduce the impact due to currents, waves and environmental. Thus, the artificial reef block is an effective method for enhancing and protecting shoreline, natural resources as well as improving fisheries and aquaculture opportunities.

The Artificial Reef can be placed near the eastern side of the temple corridor at a distance where the water depth is around 2-3 m.

Phase i: The area in the sea demarcated for Phase I artificial reef placement is shown in **Fig.7.1.** Proving artificial reef for Phase I area is about 90,000 m^2. The water depth would reduce from 2.5 – 2.0 m to 1.0 – 0.5 m thereby dissipating the wave energy considerably.

Phase II: The area in the sea for Phase II artificial reef placement is shown in **Fig.7.2.** The proposed area is about 3,63,000 m^2. In this case, the total wave energy is absorbed and they get reduced to 0.1 - 0.2 m.

This can be a permanent solution for the shore protection for the temple complex.

Advantages:

The artificial reefs can be considered as arbitration of engineering technology to recover the natural habitats, increase productivity, and manage aquatic resources in addition to shore protection. The other advantages of placing Artificial Reefs are:

- *Protection of sensitive habitats from fishing activities*
- *Restoration of depleted habitats including pearls and corals*
- *Enhancement of biodiversity*
- *Fisheries Enhancement*
- *Creating suitable areas for diving*
- *Research and educational activities*
- *Augmenting the Gulf of Mannar Bio-Reserve*

7.1. Design of Artificial Reef Block

The Geometry of Artificial Reef Block is designed in such a way that fishes can intrude in and around the artificial block. It will be a paraboloidal shape with 1500 mm bottom diameter x 1000 mm top diameter x 1200 mm height. It will be hollow inside with a wall thickness of 400 mm at bottom and 250 mm at top. It is estimated to have a mass of 2.43 tons. The construction can take up in two phases:

- *i) place 90,000 m^2 area on the destroyed reef having water depth 2.0 m to 2.5 m and*
- *ii) Place additionally another 3, 60,000 m^2 on the shallow part of the calcareous seafloor having water depth 2.0 m to 2.5 m.*

The design is concerned in a way that the block will not float in submerged condition such that it sticks firmly to the ground. The individual artificial reef unit designed for the placement on seabed is shown in **Fig. 7.3**.

7.2. Detailed Estimation

Weight & Volume of one Reef Calculation

Data:

Assume the Geometry as Frustum.
Height h = 1200 mm = 1.2 m

Bottom:

Bottom thickness, t_b = 400 mm = 0.4 m
D_1 = 1500 mm = 1.5 m
D_2 = 1500 – 400 – 400 = 700 mm = 0.7 m
$R_1 = D_1/2$ = 0.75 m
$R_1 = D_1/2$ = 0.75 m

Top:

Top Thickness, t_t = 250 = 0.25m
d1 = 1000 mm = 1 m
d2 = 1000 – 250 – 250 = 500 mm = 0.5m
$r_1 = d_1/2$ = 0.5 m
$r_2 = d_2/2$ = 0.25 m

Volume of Frustum = $\frac{1}{3}\pi(R^2 + Rr + r^2)h$ units.

Let V_1 be Volume of Outer Frustum.

$V_1 = \frac{1}{3}\pi\left({R_1}^2 + R_1 r_1 + {r_1}^2\right)h$

V_1 = 1.4922 m^3

Let V_2 be Volume of Inner Frustum

$V_2 = \frac{1}{3}\pi\left({R_2}^2 + R_2 r_2 + {r_2}^2\right)h$

V_2 = 0.3424 m^3

Volume of the block (V)

V = V1 – V2
V = 1.1498 m^3

Net Volume = V – Volume of Voids

Volume of Voids = $6\pi {r_v}^2 t_m$ units,

where r_v is the radius of void circle = 150 mm, r_v = 0.15 m,
t_m (mean thickness) = (t_b + t_t) /2, t_m = 0.325 m
Volume of Voids = 0.13784 m^3
Net Volume = V – Volume of Voids

Net Volume = 1 m^3

Density of Concrete = 2400 kg / m^3
Weight of Concrete block = Density * Net Volume
= 2400 * 1.012
= 2428.8 kg

Weight of Each concrete block = 2.4 Tons

Cost Estimation

Phase - I

Total area of seabed to be placed = 90,000 m^2

Total number of blocks = 53,000 Nos

Total volume of concrete = 53, 000 m^3

Cost of casting, lowering and monitoring per one reef = **Rs. 15000/-**

∴ Cost of construction of reef = 53,000 m^3 x Rs. 15000/- per m^3

Cost of construction for Phase I = **Rs. 80 crores.**

Phase – II

Total area of seabed to be placed = 3,63,000 m^2

Total number of blocks = 2,14,000 Nos

Total volume of concrete = 2,14,000 m^3

Cost of casting, lowering and monitoring per one reef = **Rs. 15000/-**

∴ Cost of construction of reef = 2,14,000 m^3 x Rs. 15000/- per m^3

Cost of construction for Phase II = **Rs. 320 crores.**

8. CONCLUSIONS

The beach erosion over the last 60 years had so advanced and presently the eastern side of the temple complex fall close to the high tide line. A seawall was first built in 1963 to protect the temple structures. The seawall was either periodically repaired or rebuilt but without any scientific approach and not with measured oceanographic information leading to a consistent problem and threat to the temple stability.

At present, there is a large-scale damage to the seawall and the wave run up rise into main temple corridor on spring tidal days and on monsoon days. The present study attempts to identify the cause of erosion and most suitable method for a solution. From the studies, it is found that the removal of offshore reef is caring erosion on the temple complex.

Based on modeling study, the placing or construction of artificial reef at opposite to temple complex is suggested. The proposed construction of artificial reef area is proposed to two Phases as Phase I and Phase II. The area of Phase I construction is 90,000 m^2 and Phase II construction is 3,63,000 m^2. The design of parabolic concrete hollow shells is prevented.

If the artificial reefs are placed over the area as indicated for phase I construction, it would provide good protection by reducing the wave height to **50** % of those waves approaching from the offshore. If adequate shore protection needed, then the phase II construction is required.

If the artificial reefs are placed over the area as indicated for phase II construction, it would provide adequate shelter by reducing the wave height to **90** % of those waves approaching from the offshore.

- *The cost of construction of Phase I area is approximately Rs. 80 crores*
- *The cost of construction of Phase II area is approximately Rs. 320 crores*

Thus, from all observations, the Artificial Reef can be the ergonomically best solution for controlling the impact of waves near the temple corridor as well as arresting erosion permanently. It may further help to natural resources like fisheries, aquaculture, Corals and Pearls.

9. WAY FORWARD

A) It is suggested to form an expert committee consisting of following members to study and give recommendation.

i. Prof. R. Sundaravadivelu, Institute Chair Professor, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai.

ii. Mr. M. D. Kudale, Retd. Additional Director, Central Water & Power Research Station, Pune and Member of Maharashtra Coastal Zone Management Authority

iii. Dr. P. Chandramohan, Former Scientist of CSIR-National Institute of Oceanography, Goa and presently the Managing Director, Indomer Coastal Hydraulics (P) Ltd., Chennai.

B) Carryout the flume modelling study on the stability of the anchor blocks size either from IITM, Chennai or CWPRS, Pune.

C) Carryout the Shallow seismic survey to understand the geology below the sea floor and the Side scan sonar survey to understand the surface geology of the top of the sea floor and after & before reef construction. This component would cost around 15 Lakhs but Indomer can do free of cost.

D) Directional wave measurement to be carried out for a period of one year. This survey can be taken up by Indomer, but the boat for one year has to be hired by HR & CE. This will cost comes around Rs. 1.2 Crores.

E) Involve CMFRI, Tuticorin or GOMBR, Ramanathapuram in finalizing the shape of the artificial block to be more environmental friendly for the marine organisms.

GALLERY

Shoreline at Temple complex

Survey team

Crossing Surf zone

Survey boat

Demarcation of LWL and HWL

HR & CE officers bathymetry team

என்னை நன்றாய் படைத்தனன் முருகன்

நன்றே கடல்சார் பணி செய்யும் படி