N. A. Siddiqui · Bikarama Prasad Yadav ·
S. M. Tauseef · S. P. Garg ·
E. R. Devendra Gill *Editors*

# Advances in Construction Safety

## Proceedings of HSFEA 2020

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# Contents

**Bridge Scour Analysis and Protection Methods** . . . . . . . . . . . . . . . . . . . . . . . 1
Raja and Durga Prasad Panday

**Construction Safety Culture Models and Their Effectiveness in Construction Industry: A Review** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 17
Bikarama Prasad Yadav, Agrapu Yerneesh Yeswanth, Albin C. Suresh, N. A. Siddiqui, and Devendra Gill

**Flood Frequency Analysis and the Canal Design for the Barnigad Region in the Yamuna River** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 29
Chetan Agrawal, Durga Prasad Panday, and Karan Singh Dhawai

**Utility Damage Prevention Measures During Excavation: A Review** . . . . 41
Bikarama Prasad Yadav, N. A. Siddiqui, Soumya Jain, and Dibendu V. Nayar

**Issues Faced by Women Construction Workers with Respect to Ill Health Effects, Wage Disparity and Unsecured Work Environment** . . . . . 55
Ashish Aeri, Chandrakant Singh, Abhishek Nandan, N. A. Siddiqui, P. Mondal, and Akshi Kunwar Singh

**Experimental Analysis of Pitting Corrosion in Offshore Structures** . . . . . 65
Parth Patel, Vikram Garaniya, Rouzbeh Abbassi, Til Baalisampang, and Vahid Aryai

**Prioritisation of Safety Factors in a Refinery by Intuitionistic Fuzzy Analytic Hierarchy Process** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 89
G. Suresh, V. R. Renjth, and A. B. Bhasi

**Hydraulic Design of a Water Treatment Plant—A Case Study for Devprayag Town in Uttarakhand** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 107
Rahul Silori and S. C. Gupta

**A Review of Ergonomic Risk Assessment Techniques Employed in Construction Industry** . . . . . 117
Rajneesh Patial, Himani Gusain, Bikarama Prasad Yadav, and N. A. Siddiqui

**Safety and Risk Management in Oil and Gas Industries: A Review** . . . . . 133
Anilett Benny and V. R. Renjith

**Hazards and Risk with Heavy Machineries Operation at Construction Site: Preventive Approach** . . . . . 143
Bikarama Prasad Yadav, Saara Vashishtha, and Deep Mehta

**Advancement in Recent Trends, Challenges, and Precautionary Health Measures in Diabetes Management for COVID-19 Pandemic** . . . 153
Ajay Vasishth, S. Nagaveni, Gagan Anand, and Kanchana Latha Chitturi

**An Overview on Construction and Demolition Waste Regulation and Strategies** . . . . . 163
Vishal Kumar Singh, Ashwin Malviya, Yendamuri Sivaji Raghav, and Suvendu Manna

**Mitigation of COVID-19 Through BBS Approach in Construction Sector** . . . . . 177
Kumar Ashish, Bikarama Prasad Yadav, M. B. Sharma, Abhishek Nandan, and N. A. Siddiqui

**A Study on Effective Implementation of BBS Programme Through Behaviour Maturity in FMCG Company** . . . . . 185
Prashanth Kumar Reddy, Surendar Varadharajan, and Bikarama Prasad Yadav

**Material Handling Hazards and Control Measures in Construction Industry** . . . . . 201
Bikarama Prasad Yadav, Sanket Shitole, Pradeep Kumar, Vishal Kumar Singh, and Robin V. John Fernandes

**Review on Construction Waste Management: India Versus Malaysia** . . . . . 207
Bikarama Prasad Yadav, Hemand Chandran, Sarath Ajithkumar, P. Mondal, Vishal Kumar Singh, and Vishal Sharma

**A Short Review on Impact of Urbanization on Surface and Ground Water Quality in India** . . . . . 221
Surendar Varadharajan

**Specifying Safety Instrumented System Response Time: Case Studies from Oil and Gas Facilities** . . . . . 229
G. Unnikrishnan

**Understanding the Critical Conditions During a Backdraft—A Review** . . . . . . . . 241
Sakshi Dubey and Akshi Kunwar Singh

**Advanced Technologies in Health Safety and Environment in Construction Industry** . . . . . . . . 247
Abhishek Nandan, P. Mondal, Bikarama Prasad Yadav, and K. Sai Bharadwaj

**Review of Earthquake Resilience and Safety in Building Construction** . . . . . . . . 265
Geetanjli Rani, P. A. Arun, Umar Muktar, Nitty Ann Abraham, and Shariq Ansari

**Land Pooling To Be a Tool for Land Development and Management** . . . . 279
Vibhor Goel, Rahul Silori, and Harsh Jha

**Implementation of Behaviour-Based Safety Management in Achieving Inclined Driver Safe Behaviour** . . . . . . . . 289
P. R. Sushmitha, P. A. Arun, and Madhuben Sharma

**Human Attitude Improvement at Work Place in Oil and Gas Industry Through Training a Proposed Model for Accident Reduction** . . . . . . . . 297
Mohammed Ismail Iqbal, Ibrahim Alrajawy, and Osama Issac

**A Succinct Study on the Effect of Lockdown on Air Quality of Agra (Taj City) (India)** . . . . . . . . 309
Bhawna Yadav Lamba, Madhuben Sharma, and Sapna Jain

**COVID-19 Impact on Indian Smart Cities: A Step Toward Build Back Better** . . . . . . . . 319
Neha Mumtaz and Tabish Izhar

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# Bridge Scour Analysis and Protection Methods

**Raja and Durga Prasad Panday**

## 1 Introduction

Scouring is the most used term in the field of bridge construction. What importance does this term have while going through the construction of bridges? A satisfying answer to this question would be very simple based on the data. The estimates from the record reveal that around 60% of bridge failures occur due to scour. Therefore, the word scour has a lot of importance in itself. Bridge scour is termed as the process in which the sand and gravel are present at the foot of pier or abutments are removed due to continuous water flow. The water that is moving has a large amount of current in itself which causes scour hole around the pier or abutments. Bridge scour when not monitored properly results in a severe disaster. Statistics show that around 46 out of 86 bridges failed due to scour in the United States between the years 1961–1976.

Scour affects this frontal portion of the pier. All the sand, silt, gravel and aggregates that are present in front of the pier get eroded hence resulting in the formation of scour hole. The erosion takes place due to the loose deposits at the foot of the pier. Most of the time, the extent of scouring is that high that it exposes the foundation of the pier. Therefore, the footing type and depth of the pier should be decided only after monitoring the scour and scouring conditions.

Various factors affect the rate of scouring. One of the major factors is the shape of the pier. It is seen that the most efficient shape out of square, rectangular, and circular was found to be circular as the rate of the scour is very much less when compared to other shaped piers. This is because a circular shape cuts the water current very efficiently hence producing very less impact at the foot of the piers.

The following research paper discusses the research done by different authors for mitigating scour, observations that are made in the scour depth experiments,

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establishment of equilibrium scour depth with time and lastly, it provides some economical solutions for reducing/mitigating the scour.

Hong-WuTANG performed research and experiment to find out the effectiveness of tetrahedral frames around the bridge piers during 3D flow [1]. It was observed that bridge pier scours with the help of tetrahedral frames could be mitigated as it alters the current of river flow. Flow around the tetrahedral frame can be categorized into three regions, namely the de-acceleration region near the sediment bed, an acceleration region in the middle of the water death region and restoration reason near the water surface. The region, which is directly affecting the scouring volume, is the deceleration region. The velocity magnitudes, turbulent intensities and vortices decreased in the deceleration region. Tetrahedral frames can dissipate the energy associated with the downfall and the horseshoe vortex generated around the bridge pier. The scour depth is reduced up to 50% or more when compared with the normal flow condition.

Alabi concluded from their research on bridge collar that the use of oblong collars could decrease local scouring around bridge pier that occurs because of flow separation and vortex developed around the pier [2]. It was found that collar efficacy increases with the increasing collar width and provides little long-term benefits at reducing the maximum scour depth. Maximum reduction in scours depth is found to be 78% of the scour depth without the collar (Fig. 1).

Kothyari [3] discussed the three-dimensional flow (horseshoe vortex, downward flow of water after striking) that takes place around the piers thus developing scour hole. The author discusses the Lacey–Inglis method for the computation of scour

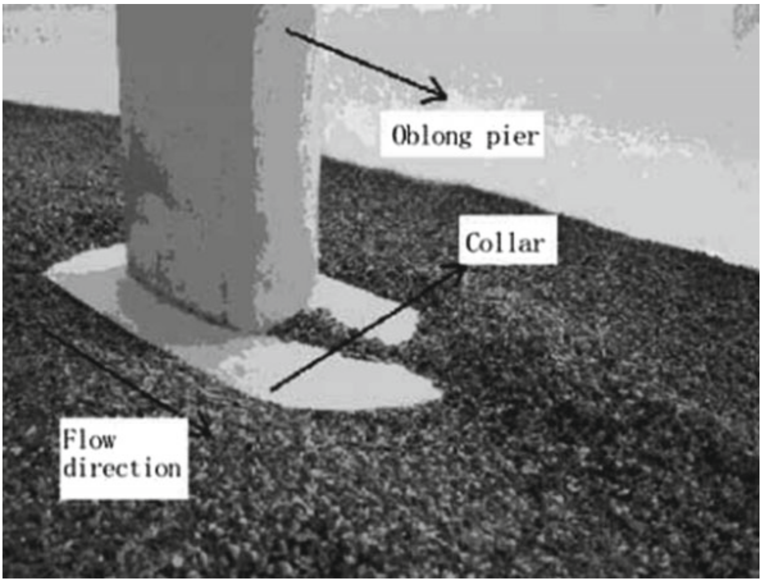



**Fig. 1** Bridge collar around bridge piers for scour protection. *Source* Alabi [2]

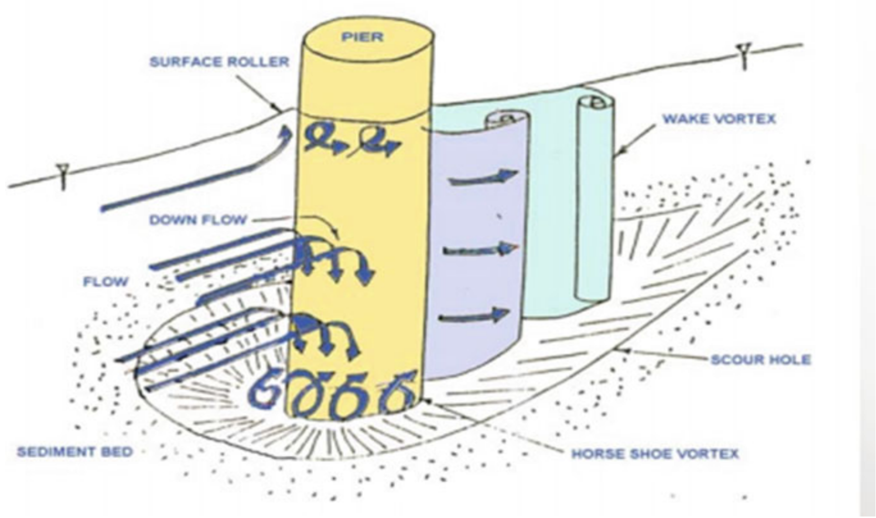



**Fig. 2** Flow structure at bridge pier. *Source* Kothyari [3]

depth. This method is recommended by IRC and Indian Railways for design purpose. The author also discusses the effect of flood on the scour depth at different intervals (Fig. 2).

R. J. Garde, U. C. Kothyari and others discussed the phenomenon of scour around the bridge pier and the needs of determining the scour [4–6]. The author enumerates the factors affecting scouring like depth of flow, the shape of pier nose, angle of inclination of the pier, incoming flow characteristics whether it is clear water flow or carries some sediment. The author talks about the relevance of the Lacey–Inglis equation and the conditions where these are used for the determination of scouring (moving bed condition). Studies have also shown that there exists a relationship between sediment size, flow depth, pier dia (max 13 m) and scour depth and shows a variation of scour depth based on these factors. At last, the author talks about the scour control and prevention method like provision of caissons or well below the pier, riprap protection method [7, 8].

## 2 Experimental Setup for the Research

The experimental setup consists of the hydraulic tilting flume with dimensions (10 m × 0.6 m × 0.75 m as length, width and depth, respectively). The flume is filled with D50 particle size (calculation is shown in the methodology section). The orifice meter is used to measure the discharge and its calibration is also shown in the methodology section. The three piers made of Perspex sheet (diameter: 5 cm and depth: 65 cm) arranged in the triangular pattern is used to study the scour. A high-resolution camera mounted appropriately is used to observe the action of the running water in the form of scouring. The scouring is studied around single pier and the three pier triangular arrangement.

## 3 Methodology

This section discusses the methodology adopted for the research. It starts with the calibration of the orifice meter, calculation of D50 sizes as the representative particle size to represent the riverbed, and finally, scour observation and the interpretation of the results.

### *3.1 Calibration of the Orifice Meter*

It is the process in which the reading of an instrument is matched to the standard values to improve the accuracy and performance of the instrument. The hydraulic tilting flume is calibrated using the standard and obtained coefficient of discharge was matched with the standard values (Table 1).

The coefficient of discharge comes out to be 0.67 (Range = 0.62–0.68). Therefore, the flume was successfully calibrated.

**Table 1** Shows the manometer readings at different time intervals

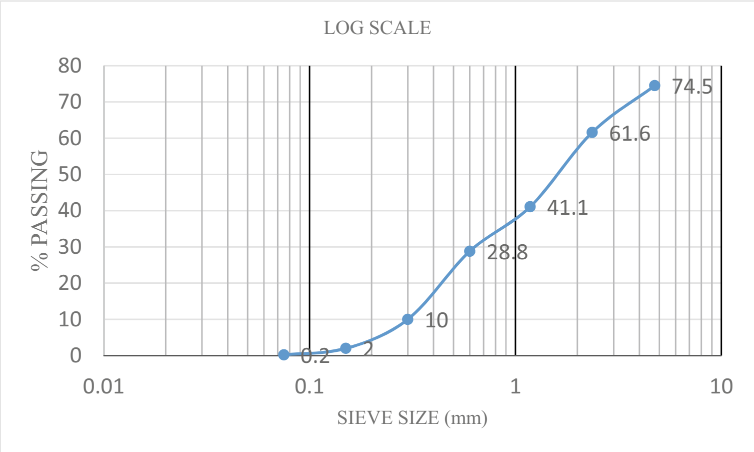
| S. No. | Manometric reading | | h, cm of water = $(y1 - y2) \times 13.6$ | Qt (cumecs) | A (Area of collecting tank) | Time taken for 10 cm rise | Qa, $m^3/s$ | Cd = Qa/Qt |
|---|---|---|---|---|---|---|---|---|
| | $y1$ | $y2$ | | | | | | |
| 1 | 58 | 90 | 435.2 | 0.0630 | 6.605 | 14.36 | 0.0459 | 0.7299 |
| 2 | 42 | 107 | 884 | 0.0898 | 6.605 | 11.56 | 0.0571 | 0.6362 |
| 3 | 39 | 110 | 965.6 | 0.0938 | 6.605 | 11.49 | 0.0574 | 0.6124 |
| 4 | 39 | 110 | 965.6 | 0.0938 | 6.605 | 10.07 | 0.065 | 0.6988 |
| | | | Average Cd | | | | | 0.669 |

### *3.2 Calculation of D50 Mean Size of Aggregate Sand at Flume Bed*

Different size aggregates were laid on the bed of the flume to notice the scour pattern around the pier. As per IRC 78-2014; the mean size of the particle (D50) should be considered for an anticipated depth of scour.

Sieve of 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 and 0.075 was taken, and sand was passed through it successively. Retained weight, percentage retained, cumulative weight, cumulative percent and pass percent were calculated and noted down after the sand was passed from all the sieves (Table 2).

A log scale graph plotting is done between pass% and sieve size to find out D50 as shown below.




The value of D50 was plotted in the logarithmic graph and it came out to be **1.692** mm.

**Table 2** Shows the different pass % of sieved sand aggregate present at the flume bed

| Sieve | Retained weight (kg) | % Retained | Cumulative weight | Cumulative % | Pass % |
|---|---|---|---|---|---|
| 4.75 | 0.255 | 25.5 | 0.255 | 25.5 | 74.5 |
| 2.36 | 0.129 | 12.9 | 0.384 | 38.4 | 61.6 |
| 1.18 | 0.205 | 20.5 | 0.589 | 58.9 | 41.1 |
| 0.6 | 0.123 | 12.3 | 0.712 | 71.2 | 28.8 |
| 0.3 | 0.188 | 18.8 | 0.9 | 90 | 10 |
| 0.15 | 0.080 | 8 | 0.98 | 98 | 2 |
| 0.075 | 0.018 | 1.8 | 0.998 | 99.8 | 0.2 |
| PAN | 0.002 | 0.2 | 1 | 100 | 0 |

### *3.3 Scour Measurement*

To understand the scouring pattern around the bridge piers, experiments were conducted at the flume bed with pier's arranged individually and in triangular pattern. A prototype pier made of plastic material with height (65 cm), diameter (50 mm) and thickness (5 mm) is used along with circular acrylic sheets. Acrylics are weather as well as impact resistant. Therefore, acrylic sheets are used for the footing of the piers. These acrylics are arranged in such a way that the pier footing resembles as stepped footing as shown in Figs. 3 and 4.

A high-resolution camera is used for recording the flow pattern around the bridge pier. Coarse aggregates of size 20 mm are used at the entrance of the flume to suppress the fine aggregate sand so that when the water enters into the flume no extra amount of sand gets eroded due to the water current. Below are the figures depicting the mounting of the camera and coarse aggregate laying (Figs. 5 and 6).

**Scour Measurement for Single Pier Arrangement**

The water is allowed to flow for at least 20–30 min so that all the moving silt particles get settled down. This would further help in identifying the scour pattern from the sidewalls of the flume. The pier is inserted into the bed sediment, and the surface


**Fig. 3** Circular acrylic sheets with inner radius 50 mm and thickness of 5 mm

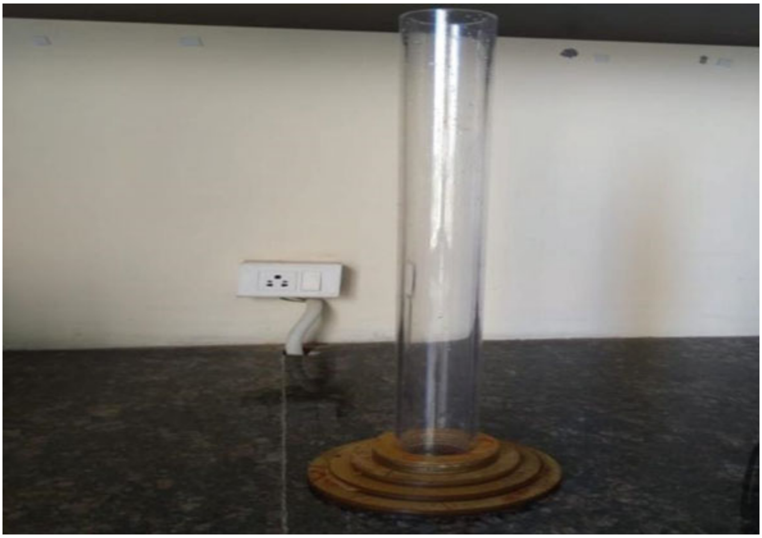


**Fig. 4** Pier equipped with stepped footing

**Fig. 5** Camera mounted above the pier for recording the flow pattern

**Fig. 6** Coarse aggregate laid at the water entry point in the flume to prevent erosion

around it is leveled. The camera is mounted just above the pier for video recording. The water is allowed to flow at 3 valve rotation and the scour pattern is noticed for each 3 min interval.

**Scour Measurement with Triangular Pier Arrangement**

The water is allowed to flow for at least 20–30 min so that all the moving silt particles get settled down. The pier is inserted into the bed sediment in a triangular pattern with a center-to-center distance of 20 cm as shown in Fig. 7 and the surface around it is leveled. The camera is mounted just above the pier for recording the flow pattern. At first, the water is allowed to flow at 4 valve rotations followed by 8 valve rotations. Consequently the scour pattern was noticed for each 5, 10 and 15 minutes interval (Figs. 8, 9, 10, 11 and 12).

## 4 Result

Results for the scour depth measurements at each pier are presented at different intervals (Fig. 13; Table 3).

**Fig. 7** Arrangement of piers in triangular pattern with c/c distance 20 cm (time interval 10 min)

**10 min Interval (P1, P2 and P3 stands for Pier 1, Pier 2 and Pier 3)**
From the graph, it can be seen that the scour depth has attained an equilibrium depth after a certain time interval. The exposed bed layer after a certain time interval is hard and well compacted, therefore, scouring at these surfaces is slow (Fig. 14; Table 4).

**5 min Interval (P1, P2 and P3 stands for Pier 1, Pier 2 and Pier 3)**
From the figure, it can be seen that equilibrium scour depth is not attained perfectly even after 10 readings. Therefore, equilibrium depth is much dependent on time. Equilibrium depth is attained after a long time once the flow starts (Fig. 15; Table 5).

**15 min interval (P1, P2 and P3 stands for Pier 1, Pier 2 and Pier 3)**.

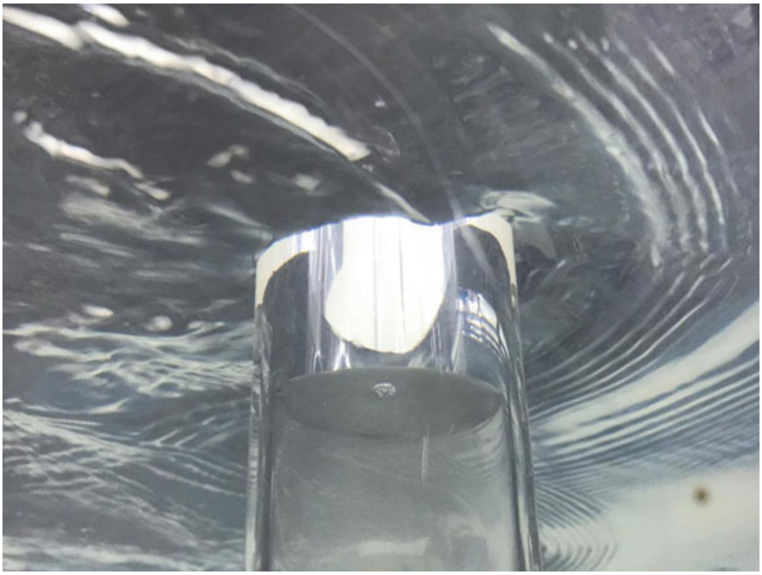


**Fig. 8** Vortex formed at 4 rotations. The water strikes the pier directly and spreads up in three different directions (three-dimensional flow, time interval 10 min)

**Fig. 9** Valve rotation 8. The footing of the pier is exposed as seen (time interval 10 min)

**Fig. 10** Due to silting and decrease in the velocity, scour depth gets decreased (10–20 min interval)

**Fig. 11** After continuous run of 90 min, footing 1 and 3 were more visible as compared to footing 2 because the width of footing 2 was more than the other two

**Fig. 12** At 8 valve rotations, water started eroding the fine aggregates present at the bed

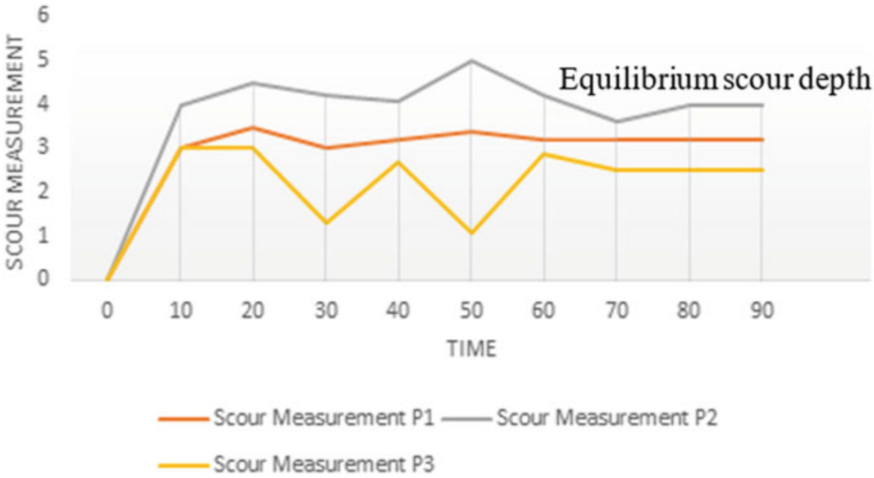



**Fig. 13** Shows the graph between scouring depth and time

**Table 3** Scour depth measurements at each pier after 10 min interval for 8 valve rotations

| Time (min) | Valve rotation | SCOUR measurement | | |
|---|---|---|---|---|
| | | P1 (mm) | P2 (mm) | P3 (mm) |
| 0 | 8 | 0 | 0 | 0 |
| 10 | 8 | 3 | 4 | 3 |
| 20 | 8 | 3.5 | 4.5 | 3 |
| 30 | 8 | 3 | 4.2 | 1.3 |
| 40 | 8 | 3.2 | 4.1 | 2.7 |
| 50 | 8 | 3.4 | 5 | 1.1 |
| 60 | 8 | 3.2 | 4.2 | 2.9 |
| 70 | 8 | 3.2 | 3.6 | 2.5 |
| 80 | 8 | 3.2 | 4 | 2.5 |
| 90 | 8 | 3.2 | 4 | 2.5 |

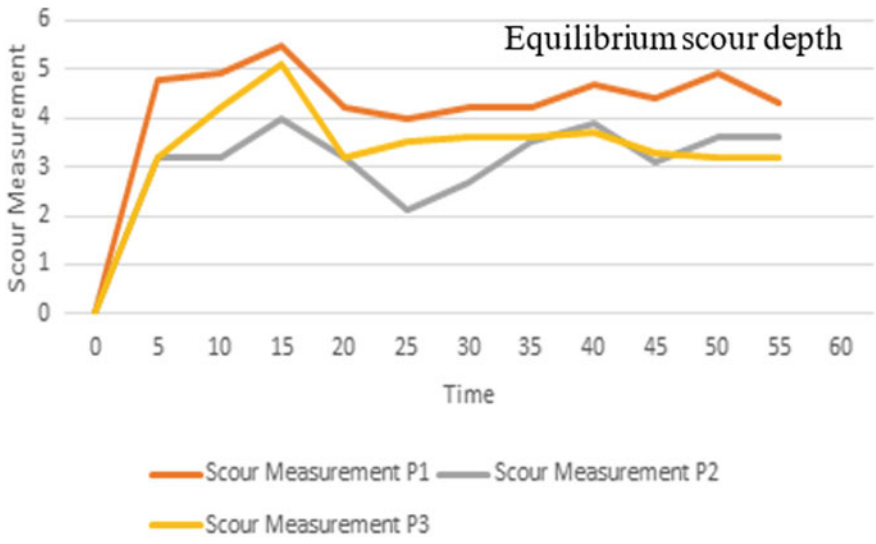



**Fig. 14** Shows the graph between scouring depth and time

## 5 Discussion and the Conclusions from the Experiment

Different observations were made during each experiment. Each observation is listed below based on the experiments accordingly.

**Scour Measurement around Single Pier pattern**

- When the water is allowed to flow through the pier at a lower speed, the rate of the scour around the bridge pier is observed to be less than the rate at the higher

**Table 4** Scour depth measurements at each pier after 5 min interval for 4 valve rotations

| Time (min) | Valve rotation | Scour measurement | | |
|---|---|---|---|---|
| | | P1 (mm) | P2 (mm) | P3 (mm) |
| 0 | | 0 | 0 | 0 |
| 5 | 4 | 4.8 | 3.2 | 3.2 |
| 10 | 4 | 4.9 | 3.2 | 4.2 |
| 15 | 4 | 5.5 | 4 | 5.1 |
| 20 | 4 | 4.2 | 3.2 | 3.2 |
| 25 | 4 | 4 | 2.1 | 3.5 |
| 30 | 4 | 4.2 | 2.7 | 3.6 |
| 35 | 4 | 4.2 | 3.5 | 3.6 |
| 40 | 4 | 4.7 | 3.9 | 3.7 |
| 45 | 8 | 4.4 | 3.1 | 3.3 |
| 50 | 8 | 4.9 | 3.6 | 3.2 |
| 55 | 8 | 4.3 | 3.6 | 3.2 |

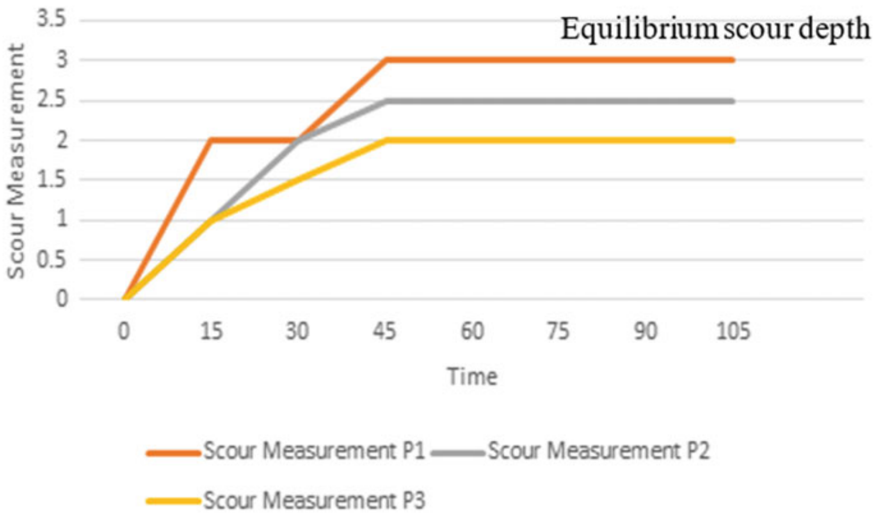



**Fig. 15** Shows the graph between scouring depth and time

flow of water. Therefore, the speed of water striking the pier surface plays a major role in the formation of scour depth.

- The exit gate of the flume was closed gradually to increase the water level in the flume for observing the effect of water level increment on the scouring. It is seen that there is no/negligible change in the rate of scour. Therefore, from this, it was concluded that the scour depth remains undisturbed during the time of flood when the water level is at its peak.

**Table 5** Scour depth measurements at each pier after 15 min interval for 4 valve rotations

| Time (min) | Valve rotation | Scour measurement | | |
|---|---|---|---|---|
| | | P1 (mm) | P2 (mm) | P3 (mm) |
| 0 | 4 | 0 | 0 | 0 |
| 15 | 4 | 2 | 1 | 1 |
| 30 | 4 | 2 | 2 | 1.5 |
| 45 | 4 | 3 | 2.5 | 2 |
| 60 | 4 | 3 | 2.5 | 2 |
| 75 | 4 | 3 | 2.5 | 2 |
| 90 | 4 | 3 | 2.5 | 2 |
| 105 | 4 | 3 | 2.5 | 2 |

- After a flow of around 30 min, there is barely any increase in the scour depth. This depth is called equilibrium scour depth.
- Scouring of bed materials occurred at the front and the side portion of piers. The rate of scouring at the backside of the pier (opposite to the flow) was observed to be very low.

### Scour Measurement around Triangular Pier Pattern

- The rate of the scour increased with time and gradually slowed down after a certain time of flow.
- Radii of scour around the bridge piers increased gradually with the passing time of flow.
- The lighter bed materials easily moved away from the course materials creating scour hole around the foot of piers.
- Therefore, from the previous point, it can be concluded that the rate of scouring also depends upon the type of bed materials present.
- The bed materials eroded from the frontal pier were deposited at the centroid of the triangular pattern thus increasing the level of the bed sediments.
- Variation in the depth of footing (2 piers with deep footing and 1 pier with shallow footing) was done and a large amount of water was allowed to flow suddenly through the flume. The results showed the pier with shallow footing could not resist the sudden shock.
- The above condition can be related to the areas where a large quantity of water flows suddenly through the channel due to cloud burst. Experimentally, it is concluded that in those conditions, the depth of the foundation should be at 1/7th of the height of the pier from the surface of the riverbed.
- In the continuous flow, if the velocity of the river is reduced suddenly, the heavy bed materials flowing along the river settle down thus reducing the depth to a very less extent.

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# Construction Safety Culture Models and Their Effectiveness in Construction Industry: A Review

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## 1 Introduction

We all know that construction sites have more hazards and hazardous jobs, so for improving the performance, we need to follow safety culture. The topmost importance of every construction company is to execute and enhance the safety of the construction site. The construction sector is distinct from other businesses in that building activities are frequently carried out outside, in hazardous situations. Construction companies all across the world are working to improve site safety [1]. Safety culture influences the overall safety of the organization, however, it is not completely clear about how it is effected and eventually influences the efficacy of the overall safety within the construction sector, and it is important to define what really means about safety culture. To ensure the safety of everyone specially the extrinsic and intrinsic elements of the culture that change people's attitudes and behaviors. All activities involving internal and external parts of the organization will be imbued with organizational culture. This information will then be distributed to all members of the organization. Construction sector works, managerial practices and the structure of work vary differently from other sectors and compared to other sectors maintaining safety at construction sector is challenging mainly due to inconsistent and dynamic working environment throughout the organization [2].

Construction industries have its own unique characteristics when compared with other industries due to the worker's attitude towards safety, the construction organizational structure, the managerial attitudes, the way of carrying out the construction

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projects as well as the environment in which they are working and developing a model towards the construction safety culture depends on these characteristics, and the effectiveness of the model depends on how these characteristics are valued. In most of the construction sites, various activities will be carried out in parallel sharing of the work spaces simultaneously as a result, the construction works may shift from place to place as the project proceeds and due to these characteristics, the workers may need to take important decisions individually and may result in undesired output. The responsibility of maintaining safety at the construction site is dependent on various factors like procedures, methods and techniques used and the management attitude towards safety. As a result, managing safety at construction sites is rather difficult compared to other industries [2].

"Safety culture" first came from the nuclear report of 1986 Chernobyl disaster, now, it is used commonly throughout industries as a term to determine the industry's atmosphere towards safety. At high-risk industries like construction sites, safety must be a number one priority and the safety culture attitude is taken from the corporate culture including personal mentality towards the safety. Safety culture is not only affected by the corporate culture but also the other non-safety-related operations of the organization. Safety culture has its own importance and impact in a construction industry but understanding the measurement of safety culture as well as managerial practices, the organizational attitude towards safety, the measurement of safety culture are the issues regarding maintaining the safety culture in a construction sector. The reputation of the construction sector is determined by its safety culture and improving the safe work environment will increase the total productivity of the company eventually. In this paper, various models of construction safety culture are studied along with the factors influencing them to improve the overall health and safety performance of the construction site [3, 4].

## 2 Literature Review

This paper describes what safety culture is, and how it influences behaviour of the worker. According to R. M. Choudhry, S. Mohamed and D. Fang, for the construction industry, the phrase safety culture is a different study but it has major attention because it deals with both the behaviour of management and attitude of the worker. This paper also describes a systematic conceptual framework, firmly rooted in appropriate academic and applied literature, to deal with an absence of verifiable process for analysing the culture of building safety. It investigates the principle of safety culture, as well as other but related concepts including the security environment, behaviour-based safety and the security system. The model in this paper is also compared with currently existing security culture models in order to emphasize its functionality on construction sites. According to Glendon, organizational culture is defined as the difference between management and workers' way of thinking. It also describes that further studies should focus on some new strategy to describe the patterns by which safety culture deviates or be influenced by other safety factors [2, 5].

There are many other models discussed in this paper like "Total safety culture model", "Socio-Technical model", "Safety Maturity Model" and "Reciprocal Safety Culture", each models has their own methodology and all models deals with the same theme like behaviours of management and workers. The total safety culture model consists of a safety triad which includes three factors like environment, person and behaviour. Likewise, different models have different factors. On the other hand, there are definitions like safety climate and safety culture. Organizational culture theory indulges with practices that affect the workers' behaviour. Almost all industries are trying to increase the importance of safety culture in return it helps the organization to minimize their accident potential [6, 7].

## 3 Safety Culture in Construction Industry

Present new findings in the sector of safety management have given rise to a new perspective on safety. Implementing safety culture within the construction industry is related to many issues regarding the workers as the problems include the skill level of workers, and the unsafe acts that are performed by the workers and the increase of worker turnover within the construction sector. More focus is being placed on ensuring that everyone recognizes the significance of safety, with the difficult challenge of altering attitudes and behaviour. Safety is not solely the duty of the manager; everyone must contribute [8, 9].

As we all know that construction projects conducted are with a high-risk atmosphere, there is a difference between construction safety culture and traditional organizational safety culture. Throughout the formation of safety culture, both external and internal factors of culture will have effect on the organization's culture. This is not to say that the safety system is not important in our present world, but it will only work properly if the firm has built a safety culture. Over time, the law has evolved to place a greater emphasis on workplace safety. The laws and regulations are still being improved today to ensure a safe working environment. Aside from the impact of laws, several safety activism variables, including the active engagement of trade unions, consumerism and the legal battles waged by accident/incident victims, influence modern managers' safety. All of these reasons are prompting management to rethink their safety policies because the safety in the workplace will be improved [1, 10].

# 4 Definitions

## 4.1 Safety Culture

Safety culture is defined by many authors and has the same theme which goes through how worker's attitude is affected by companies' culture. The accident on 26 April 1986 at Chernobyl was a major one and the meeting conducted after this accident submitted a report in which the phrase safety culture was used first. Simply we can say that safety culture is common practice given to a group of employees and this includes both the behaviour of the management and behaviour of the employee. Mohamed described that organization culture has a sub-branch which is safety culture [2, 11].

## 4.2 Safety Climate

Safety climate is defined as a summation of the insight that workers share about their workplace environment, and safety climate gives an actual idea of how safety culture is carried out in an organization. Safety culture as well as safety climate are not much different from definitions as these two are different approaches towards creating an importance of safety within the organization, and if the safety culture is efficient, then it directly reflects the safety climate of the organization [2, 12].

## 4.3 Safety Commitment

One of the best ways to make a workplace safe is by start practicing all the rules and procedures set by the organization. In order to make that possible, each and every personnel starting from the management to workers, everyone should practise these safety norms in their everyday life when they step into the workplace. For achieving this, a strong commitment from each and every personnel in the organization is necessary. Developing a stringent commitment towards safety from the workforce can reduce the injuries and fatalities by a huge margin. According to a study conducted by OSHA, the organizations performing safety awareness, safety training, etc. tend to have a decline in the injury and fatality rate. So by developing this safety commitment to ourselves and to others, each and every one in the organization starts to feel like a family. Moreover, it will induce a positive culture in the organization. A good and harmonious workplace atmosphere will create a sense of belongings to the workers which will increase the morale of the workers. So after all, the word "Safety Commitment" is the stepping stone towards achieving a safer workplace [13].

## 5 Measures of Safety Performance

Safety performance measures to provide information on how well the safety is carried out within the organization as well as current performance level. In a construction sector, due to various activities, various hazards will be present and these hazard levels are measured and these inputs will give information regarding the effectiveness of the control measures applied to reduce the hazards. The health and safety management system will evolve from the initial principles as per time and is measured by evaluating the existing policies and the organizational structure regarding the planning and implementation of safety. Different parts of the organization will have various plans and these must be aligned together in order to provide overall aim towards the safety of the organization. The health and safety management systems: measuring health and safety at workplace is a continuous process and these techniques must be carried out in a effective manner. The frequency of these measurements which are to be carried out must be planned [2, 10].

## 6 Safety System

Safety system of work is a written procedure that is made from evaluating the present and possible hazards and risks associated with in the construction work site. This results in the identification of a safe system of work to be carried out, safe operating procedures (SOP) will establish a fixed method for executing the activities. SOP is a written procedure which describes the step by step instructions on how to perform a task with safety including sequence of jobs to be carried out, evaluating potential hazards and risks, recommended control measures, personal protective equipment (PPE) to be carried with the task and how to perform the task. Safety policy and goals, safety regulations and objectives, scheduling and work organization, execution and regular operating practice, tracking, responses and inspections, remedial action, evaluation and continuous improvements are the vital components of a system that represent safety in a construction sector are shown in Fig. 1. The system encompasses more than documentation areas as it describes the real execution of various activities and practices. A safety system includes all policies, objectives, roles, duties, accountability, codes, regulations, interactions, methods, techniques, instruments, information and records for safely managing site operations [2].

## 7 Behaviour-Based Safety (BBS)

This approach mainly deals with systematic approach of utilization, studies on psychology and human behaviour. BBS method is described as a bottom up approach along with the support of safety leaders. It is a data-driven or analytic method in which