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ARTICLE

Repair and Restoration of the Historical Wellesley Bridge at Srirangapatna: A Case Study

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ABSTRACT

The Historical Wellesley Bridge, built by the Krishnaraja Wadiyar under the supervision of Dewan Purnaih across river Cauvery at Srirangapatna. Situation of bridge is got when heavy rainfall followed by heavy inflow from Cauvery Catchment area in Kodagu District. At present, the Government of Karnataka has taken measures to do the restoration works using the same previously used materials with slight changes. Hence, in the present investigation the authors are doing a case study on the above structure by testing the ingredients of the materials used for it and also by conducting Non-Destructive Test on the structure to know its strength before and after restoration. Based on the test results obtained, the authors will give a conclusion with respect to durability aspects. In addition to the above, the authors will test for few alternative materials i.e., lime mortar with Cement (i.e. MM2 Grade Masonary mortar). Finally, from the obtained test results here the authors can suggest suitable material for the structures.

1. Introduction

The system via which limestone (calcium carbonate) is converted to quicklime with the aid of heating, then to slaked lime by using hydration, and clearly reverts to calcium carbonate via carbonation is referred to as the lime cycle. The situations and compounds present all through each step of the lime cycle have a robust effect of the end product, therefore the complicated and varied physical nature of lime products.

An example is whilst slaked lime (calcium hydroxide) is blended right into a thick slurry with sand and water to shape mortar for building functions. Whilst the masonry has been laid, the slaked lime inside the mortar slowly begins to react with carbon dioxide to shape calcium carbonate (limestone) in line with the reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

The carbon dioxide that takes component in this reaction is mainly available in the air or dissolved in rainwater so natural lime mortar will now not re-carbonate beneath water or internal a thick masonry wall.

The lime cycle for dolomitic and magnesium lime is

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not nicely understood but greater complex because the magnesium compounds additionally slake to periclase which slake more slowly than calcium oxide and whilst hydrated produce several different compounds hence those limes comprise inclusions of portlandite, brucite, magnesite, and other magnesium hydroxyl carbonate compounds. Those magnesium compounds have very constrained, contradictory research which questions whether they may be substantially reactive with acid rain that could result in the formation of magnesium sulphate salts. Magnesium sulphate salts may also damage the mortar when they dry and recrystallize because of expansion of the crystals as they shape that is called sulphate attack.

Because lime has an adhesive property with bricks and stones, it is regularly used as binding material in masonry works. It is also utilized in whitewashing as wall coat to adhere the whitewash onto the wall.

Generally talking the trouble of recuperation of these buildings differs substantially from the trouble of repair and strengthening of regular buildings. For enormous buildings emphasis is given to the maintenance in their aesthetic and historical values, even as the assignment to remain in use may be considered of secondary importance, and anyhow because of the effort in the direction of fulfillment of the main project [1].

The problems associated with the healing of antique stone bridges are numerous but the civil engineer must take under be aware every technique and agent which can be applied in every separate case due to the notable importance of those structures [2].

The presence of damage, specifically cracking, isn't always inevitably a sign of danger, since it may produce most effective a redistribution of stresses, for which failure chance might be absent. Despite the fact that, while harm threatens protection of historic bridges, it becomes important to assure their structural balance, by way of sporting out restore and strengthening measures, stimulated through both the significance they nevertheless count on in the real street network and the architectural, ancient or social value they represent [3].

The masonry walls and pillars subjected to compression are the most important elements of the ancient masonry buildings. It is necessary to take into consideration reliability techniques to reap correct compressive energy substances which the structures had been erected. Because of the ancient person of many masonry centers, the possibilities for casting off the best number of samples are confined [4].

2. Literature Review

Rutika Bhoir and Yogesh Bhoir (2019) carried out repair and rehabilitation of a building by considering the building as a case study and checked the existing building components majorly to find out the current structural performance and condition. The investigation is mainly based on visual inspection of the building and Non-Destructive Tests (Rebound Hammer). In this investigation, they have conducted three tests i.e., ultrasonic pulse velocity test, rebound hammer test and carbonation test techniques. The detail investigation for the building with all NDT test results indicated that there is a variation in the compressive strength of concrete in beams as well as in column members. At certain locations of the building, the compressive strength found around 10MPa which indicating poor quality of concrete adopted at the time of execution of the building which increases the permeability of the concrete leading to allow the harmful gases such as carbon dioxide gas, chlorides etc. from the outside environment resulting in corrosion effect for steel leads to decreases the durability of the structure.

M. Karaveziroglou-Weber, et al. (2017) conducted study on the repair of an old stone bridge, where this investigation deals with the restoration and rehabilitation of an arched bridge situated in Central Greece. This stone bridge, built in the 18th century, with its elegant form is an excellent reminder of the Greekarchitectural heritage in Central Greece. This bridge was seriously damaged due to aging and, earthquakes, floods and some interventions but there is no serious attempts of restoration has made. The restoration works suggested through this paper includes - the pathology of the existing bridge and its analysis, considering only the dead loads and taking the consideration of seismic actions and the proposals for its repairing and strengthening was made. For that, various data's were considered along with in situ investigations and laboratory tests.

Daniel V. Oliveira and Paulo B. Lourenço conducted the study on the repair of stone masonry arch bridges. This investigation deals with the analysis and design of repair measures for two Portuguese masonry arch bridges. The first one is related with a masonry bridge constructed in the 19th century. It composed of six stone arches and which located in the centre city of Portugal. The second example is a medieval masonry bridge consisting of three semi-circular stone arches and which is located in the North of Portugal city. Repair measures are adopted to establish the safety of the bridge and these measures were taken in order to respect the modern principles of structural intervention in architectural heritage.

Rodrigues et al. (2008) deals with some diagnostic testing, conservation, maintenance and rehabilitation recommendations for existing masonry bridges with special attention to the historical bridges. They have done rehabilitation work on the steel bars, joint repointing, and injection of the fill material, waterproofing drainage of pavement and dismantling and re-construction. This investigation finally concludes that the many of these recommendations are very easy and it is common to apply. However, there are some of them that must be well planned and analysed before application to avoid the destruction and/or deprive the performance of bridge and its characteristics.

Aditya S. Gangane and Pravin V. Khandve (2015) conducted the extensive study on special repair techniques by using some special material for waterproofing, grouting, protective coatings and chemical adhesive. The old plastering was chipped and fresh plastering should be suggested in order to avoid the bridge among the plasters. These techniques are new and which involve an appreciable amount of money generating which is required for trainee skilled labours and supervision by trained personnel to increase the better workmanship. The demand of restoration can be achieved by enhancing the life and look of the structure. In such cases, the special repair work, good quality of special chemicals admixtures, grouts material should be used systematically to manage the activities pertaining to 4M's will certainly leads to good results and work with economy and sustainability.

Ladislav Klusaceka et al. (2017), carried out the restoration of arch bridge by additional horizontal pre-stress to the structure, by adopting the methods of strengthening the arch bridge that has longitudinal cracked. The process of this is done by inserting reinforced concrete spandrel walls which was stabilized by transverse pre stressed mono strands. Specifically, their aim is to reconstruction of the brick arch railway bridge, which was in disrepair. At the beginning of the design work it had to be decided whether it would be effective to carry out reconstruction of the existing bridge, or to accede to build a new bridge on the existing place. The test results indicate that experimental measures and the engineering numerical models confirmed to the high effectiveness of introducing the pre stress into the bridge arch as well as suitability of using. After introducing the pre-stress, the separated parts of the bridge began to work as one unit again, and a part of the stress on the arch is carried by attached concrete front walls.

The Department of Transportation for the state of Iowa (Wipf. et al. -2003)conducted research work that focused on the maintenance, repair and rehabilitation methods for bridges. They have conducted research on substructure member's that is pile repair for the bridge. There is no consideration placed on analysing cost or life data for the provided repairs. In addition to that, the repairs are not objectively compared to one another for the purposes of deciding which repair would be the most effective and efficient for a given element. This study also provides useful information about how repairs should be conducted, but never analyses them in terms of efficacy or estimated life.

Literature Survey Outcomes

After going through literature review, it depicts that the historical structures are needed to maintain with good condition - hence, the restoration of these structures is very much necessary. Cauvery River at Srirangapatna by testing the materials used for restoration and by checking the strength of the structures through Non-Destructive Test before and after restoration. Also, here we are testing few alternative jointing materials i.e., lime mortar with cement (MM2 Grade Masonary Mortar).

3. Objectives

- To determine the strength of the jointing material i.e., lime mortar which will be used for restoration works.
- To check the strength of the existing structure before and after restoration using Non-destructive Test.
- To predict the durability of the structure based on the test results obtained.
- Finally, a Scanning Electron Microscopic (SEM) test will be done on the jointing material to visualize the microstructure of it and in turn the obtained output will be helpful to know the reason beyond the variations of the strength.

4. Methodology

- Site visits and site Observations.
- Collection of materials.
- Non-Destructive Test on structure before restoration.
- Testing on materials.
- Non-Destructive Test on structure after restoration.
- To predict the durability of the structure after restoration.
- Scanning Electron Microscope test on jointing material.

4.1 Basic Tests on Materials Used for Repair and Restoration

4.1.1 Fine Aggregates: (Specific Gravity)

The specific gravity of the fine aggregate (i.e. sand) is calculated as the ratio of the weight of given volume of aggregates to the weight of equal volume of standard liquid (i.e. water). The test is conducted according to IS: 2386 (part 3) -1963 and the experimental setup has been shown in Figure 1.

$$\text{Specific Gravity} = \frac{\text{wt of given volume of Aggregates}}{\text{wt of equal volume of water}}$$

Specific Gravity determination is one of the most important tests to be conducted. There are particles which are lighter or heavier than aggregates, tracking of Specific gravity can help us identify if the aggregates are up to the standards or if there are any possible contaminations. Contaminations can be dangerous for the lime mixture.

The specific gravity of taken sands is considered to be around 2.65 after the basic test on Specific gravity.

Observation and calculation

Wt. of empty bottle (W_1) = 615 g

Wt. of empty bottle and cement (W_2) = 1124 g

Wt. of empty bottle, sand and water (W_3) = 1786 g

Wt. of empty bottle and water (W_4) = 1469 g

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{1124 - 615}{(1469 - 615) - (1786 - 1124)}$$

$$\text{Specific gravity} = 2.65$$

Figure 1. Pyconometer

Result: The specific gravity of the fine aggregates is **2.65.**

4.1.2 Sieve Analysis

Sieve analysis helps in determining the grain size distribution of both fine and coarse aggregates. As per the recommendation of IS: 2386 (Part I) – 1963.

To determine the suitability of aggregate for making Lime Mortar. Aggregates to be used for making Lime Mortar should be of a known gradation so that good compact Lime Mortar can be made Sieve analysis is one of the important tests conducted while performing design of Lime Mortar mix Indian standard test sieve of different sizes. Weigh balance capable of weight within 0, 1% of weight of specimen. The sieve analysis on fine aggregates is done according to IS: 2386 (part 1)-1963. The zone of the fine aggregates is determined by plotting the graph of the values obtained and is represented in Table 1 and also in the form of graphical representation shown in Graph 1.

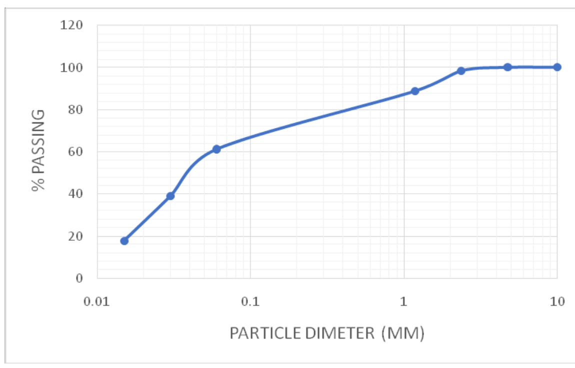
Observation:

- Weight of dry sample = 1000 g

Table 1. Sieve analysis

Size of the sieve (mm)	Soil Retained (g)	cumulative weight retained	Soil Retained (%)	Soil Passing (%)
10.00	0	0.0	0.0	0
4.75	0	0.0	0.0	100.0
2.36	16	16.0	1.6	98.4
1.18	96	112.0	11.2	88.8
0.06	276	388.0	38.8	61.2
0.03	222	610.0	61.0	39.0
0.015	211	821.0	82.1	17.9
PAN	179	1000.0	100.0	0.0
TOTAL:	**1000**		**327.8**	

Graphical representation



Graph 1. Sieve analysis graphical representation

Result: The fine aggregate belongs to **ZONE III.**

Fineness Modulus (FM) of sand:

$$\frac{\text{Sum of cumulative \% wt. retained}}{100} = \mathbf{2.94}$$

4.2 Surkhi

4.2.1 Specific Gravity Test on Surkhi

Specific gravity of Surkhi is the ratio of the Wt. of given volume of aggregates to the weight of equal volume of water used. The test is conducted according to IS: 2386 (part 3) -1963.

$$\text{Specific Gravity} = \frac{\text{wt. of given volume of aggregates}}{\text{wt. of equal volume of water}}$$

Specific Gravity determination is one of the most important tests to be conducted. There are particles which are lighter or heavier than aggregates, tracking of Specific gravity can help us identify if the aggregates are up to the standards or if there are any possible contaminations. Contaminations can be dangerous for the Lime Mortar mixture. The specific gravity of Surkhi is considered to be around 2.7.

Observation and calculation

Wt. of empty bottle (W_1)	=	615 g
Wt. of empty bottle and cement (W_2)	=	1050 g
Wt. of empty bottle, sand and water (W_3)	=	1743 g
Wt. of empty bottle and water (W_4)	=	1469 g

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{1050 - 615}{(1469 - 615) - (1743 - 1050)}$$

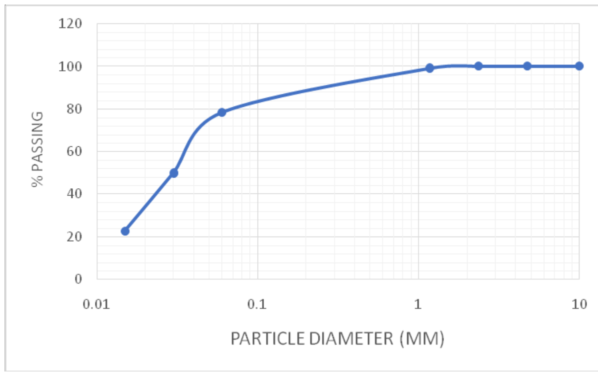
$$\text{Specific gravity} = 2.70$$

Results: The specific gravity of the fine aggregates is **2.70.**

4.2.2 Sieve Analysis of Surkhi

To determine the suitability of aggregate for preparing concrete. Aggregates to be used for making concrete should be of a known gradation so that good compact concrete can be made Sieve analysis is one of the important tests conducted while performing design of concrete mix Indian standard test sieve of different sizes. Weigh balance capable of weight within 0, 1% of weight of specimen. The sieve analysis on fine aggregates is done according to IS: 2386 (part 1)-1963. The zone of the fine aggregates is determined by plotting the graph of the values obtained are represented in Table 2 and also in the form of graphical representation shown in Graph 2.

Graphical representation



Graph 2. Sieve analysis graphical representation

Result: The fine aggregate belongs to **ZONE III.**

Fineness Modulus (FM):

$$\frac{\text{sum of cumulative \%wt. retained}}{100} = \mathbf{2.5}$$

4.3 Lime

Fineness test for Lime

The Fineness Test of lime is done by conducting the sieve analysis for lime sample through standard IS sieves of different sizes recommended by IS 6932(Part IV) -1973.

$$\text{Fineness (\%)} = \frac{\text{Residual lime on sieve in g} \times 100}{\text{Initial taken sample}}$$

$$= \frac{5 \times 100}{100}$$

$$= 5\%$$

Percentage of fineness of lime is 5%.

Observation:

Weight of dry sample = 1000 g

Table 2. Sieve analysis for Surkhi

Size of the sieve (mm)	Soil Retained (g)	cumulative weight retained	Soil Retained (%)	Soil Passing (%)
10.00	0	0.0	0.0	0
4.75	0	0.0	0.0	0
2.36	0	0.0	0.0	0
1.18	9	9.0	0.9	99.1
0.06	208	217.0	21.7	78.3
0.03	284	501.0	50.1	49.9
0.015	273	774.0	77.4	22.6
PAN	226	1000.0	100.0	0.0
TOTAL:	**1000**		**327.8**	

5. Results and Discussions

5.1 Workability Test

The Lime slump test measures the consistency of fresh lime before it sets. It's miles achieved to check the workability of freshly made lime, and consequently the convenience with which lime flows. It may also be used as a trademark of an improperly mixed batch. Inside the case of hydrated lime, the lime putty will be organized by means of thoroughly blending the hydrated lime with an identical mass of easy water at a temperature of 27 + 2'C, 24 hours earlier than the following operations. A convenient quantity of hydrated lime to be taken for this cause shall be 500 g. At the expiry of 24 hours the soaked fabric shall be thoroughly combined and knocked up to provide a plastic putty. A mixer of the sort given in IS 1625.1971 shall be used for the knocking up the cloth being passed two times through this mixer. The lime putty organized will be adjusted to traditional plastering consistency, which will be that indicated by way of an average spread of the decrease part of the lime putty to 11 cm with a permissible deviation of now not extra than zero.1 cm, while subjected to one bump on the standard flow table.

Size of the mould: Top diameter = 40 mm
Bottom diameter = 65 mm
Length = 90 mm

Results: The average spread of 11 cm is obtained at the water content of 180 mL.

5.2 Determination of Initial Setting Time

Initial setting time is regarded as the time elapsed between the moments that the water is added to the lime, to the time that the paste starts losing its plasticity. Place the test block prepared in accordance with 3.2.4 of IS: 6932 (Part-8)-1973. Under the rod bearing the needle (C), lower the needle gently in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block. In the beginning, the needle will completely pierce the test block. Repeat this procedure until the needle, when brought in contact with the test block and released as described above, fails to pierce the block by 5 +0.5 mm measured from the bottom of the mould. The period elapsing between the time when water is added to the lime and the time a: which the needle fails to pierce the test block by 5 +0.5 mm shall be the initial setting time. (After achieving 11 cm spread as done in workability, lime mortar is set for initial setting).

5.3 Determination of Final Setting Time

The final setting time is the time elapsed along the moment the water is introduced to the lime, and the time when the paste has absolutely misplaced its plasticity and has attained sufficient firmness to resist certain particular stress. Determination of final setting Time - replace the needle (C) of the Vicat equipment by the needle with an annular attachment (F). The lime shall be considered as ultimately set when, upon making use of the needle gently to the surface of test block, the needle makes an impression on the surface of test block even as the attachment fails to accomplish that shall be the very last setting time. Within the event of a scum forming at the surface of the check block, use the bottom of the block for the determination. The results obtained after the test conduct are represented in Table 3 with respect to time consideration.

Table 3. IST and FST in Minutes

Sl. No	Reading	Time in minutes
1.	5mm from bottom	1680
2.	0	4320

5.4 Compressive Test

While hydrated lime is used, 500 g or the sample will be very well mixed with 60 to 65 percent of water for five minutes, and the resulting putty shall be surpassed twice through a mixer of the kind given in IS: 1625-1971 and used right away for preparing the standard mortar. Blend 350 g of the putty with an amount of standard sand equal to a few times the mass of the dry hydrate contained in it, this is, 636 g to 656 g. The balance of the putty shall be discarded. The lime putty and sand will be thoroughly combined for 10 mins continuously, so one can form a uniform plastic mortar. Twelve cubes with 50 mm width-0 cm will be prepared from standard lime-sand mortar. The specimens will be taken out of the moulds and located inside the air inside the laboratory for four days, while 7 days old, the specimens will be immersed in clean water and left there until simply previous to trying out for its strength in the testing machine. After 7 days of storage in water of the cubes will be taken out of water, wiped surface-dry and examined for compressive power in a compression testing machine. This offers the strength at 14 days. The final 6 test specimens shall be taken out after 28 days and in addition tested accordingly determining the compressive strength at 28 days. The load will be step by step and uniformly implemented, starting from zero growing on the charge of 15 kg/min. (IS 6932 (part XI) –

1973). Size of the cube: 50 × 50 × 50 mm. Cast cubes were tested for 14 and 28 days curing period and the results were tabulated in Table 4 & Table 5.

Table 4. Compressive Strength of Concrete for 14 Days Curing

Sl.no	Material	No of Days	Area of cube (cm^3)	Compressive Load (kN)	Compressive Strength	
					N/mm^2	Kg/cm^2
1	LIME	14	25	2.5	1.0	10
2		14	25	2.8	1.1	11
3		14	25	2.5	1.0	10
4		14	25	2.3	0.9	9
5		14	25	2.8	1.1	11
6		14	25	2.5	1.0	10

Size of the cube: 50 × 50 × 50mm

Table 5. Compressive Strength of Concrete for 28 Days Curing

Sl.no	**Material**	**No of Days**	**Area of cube (cm3)**	**Compressive Load (KN)**	**Compressive Strength**	
					N/mm2	**Kg/cm2**
1	LIME	28	25	3.8	1.5	15
2		28	25	3.5	1.4	14
3		28	25	3.8	1.5	15
4		28	25	3.8	1.5	15
5		28	25	3.8	1.5	15
6		28	25	3.5	1.4	14

Result: The compressive strength of Lime Mortar at 14 days is $1.01N/mm^2$.

The compressive strength of Lime Mortar at 28 days is $1.46N/mm^2$.

5.5 Experimental Procedure

5.5.1 Batching

The quantity of materials was batched accordingly to the results obtained from the code book IS 2250-1981. This ensures the usage of required quantity of materials. Weigh batching is the proper and preferred method of measuring concrete ingredients which leads to more uniform proportioning. Weigh batching system allows simplicity, flexibility and accuracy. Exclusive varieties of weigh batchers available in the marketplace and it depends upon the form of task. Manual weigh batching, in manual batching weighing of all lime mortar ingredients is done manually. This system may be used for small jobs. For the project manual weigh batching was adapted as shown in the Figure 2. Weigh batching has a great advantage as it gives good quality of lime mortar and providing more accurate and consistent mixture.

Figure 2. Weigh Batching Lime

5.5.2 Mixing

Complete blending of the materials which are required for the production of a homogeneous lime mortar. This can vary from hand to machine mixing. The materials were mixed using hand mixing to ensure the uniform mix of lime, Sand, Surkhi, Jaggery, Soap Nut, Egg and water was added to the mix.

5.5.3 Placing of Lime Mortar

The uniform blend obtained from the mixer was placed in the moulds manually. Oil was applied to the mould in order to ease the demoulding process. The Lime mortar was placed in layers and then compacted using thumb to ensure good compaction and uniform texture. After finishing manually, it was found hand compaction gave better results as shown in Figure 3.

Figure 3. PLACING

5.5.4 Finishing

The top of the mould i.e. the bottom of the lime mortar cube was finished evenly using a trowel to get a smooth and level bottom surface. This ensures the lime mortar cube to be in a levelled surface in order to have a levelled surface after placing as represented in Figure 4.

Figure 4. Finished Lime Mortar

5.5.5 Demoulding and Curing

The cube from the moulds were demoulded after 3 Days of casting. The lime mortar cube was kept in laboratory for 4 days, reaming days it is kept for curing and maximum gains in strengths are secured in the first 14 to 28 days of curing. These cubes were immersed in curing tanks for 21 days (or 7 days) for curing shown in Figure 5.

Figure 5. Demoulding and kept For Curing

5.6 Tests on Jointing Material Used for Restoration

The following are the tests conducted on Jointing Materials and as follows:

a) Compressive Strength

b) Consistency of Masonry Mortar

In addition to above tests Non-Destructive Test and Scanning Electron Microscopic test are also carried out.

5.7 Test Conducted for Lime Masonry Mortar at Site

The Compressive Strength of Lime Masonry Mortar used at Site as given in below Table 6:

5.8 Test Conducted in Laboratory- Compressive Test (Testing on Jointing Materials)

Lime is typically strong compression but much less than concrete and in real construction, the concrete is used in compression. Lime except strong in compression is likewise appropriate in different characteristics. Higher the compressive strength higher is the durability. Bond strength additionally improves with the boom in compressive strength.

The Classical method by crushing specimens within the compressive testing device the compressive strength is obtained as the take a look at results. Consequently, its miles a right away test technique that's globally standardized. Collectively with the modulus of elasticity, the compressive energy is the most important belongings of Lime mortar. Cube strength will be laid out in terms of 14 days and 28 day's compressive strength. Individual cube strength shall now not be less than 85 percentage of specified strength. The required common compressive strengths of different grades of paver blocks are given in desk 1 of IS 712 -1981 as shown in Figure 6.

Figure 6. Compressive Strength Testing Equipment

Table 6. Compressive Strength of Lime Masonry Mortar used at Site

Block Number	No of Days	Length in mm	Breadth in mm	Area in mm^2	Ultimate Load (KN)	Compressive Strength (Mpa)
1	28	50	50	2500	4	1.62
2	28	50	50	2500	4	1.60
3	28	50	50	2500	4	1.62

Result: The Compressive Strength of lime masonry mortar at site is 1.61 Mpa.

Compression Test Results

The compressive strength test results were shown in below Table 7.

5.9 Grade of Masonary Mortar

Masonry mortars shall otherwise be specific via the grade in terms of their minimal compressive strength as given in Table1 (IS 2250-1981). Masonry mortars in terms of mix proportion which gives the range of compressive strength (at the age of 28 days) values are also given in Table 1 for guidance.

Criteria for Selection of Masonry Mortars

In the case of masonry exposed often to rains and where there may be similarly safety by means of manner of plastering or rendering or other finishes, the grade of mortar shall no longer be much less than MM 0.7 but shall rather be of grade MM 2. In which no protection is supplied, the grade of mortar for outside partitions shall insurrection is less than MM 2 which is represented in Table 8.

For MM2 Grade Masonry Mortars take 1 component Cement, 2 a part of Lime and nine part of sand (1:2:9).

In the case of masonry exposed often to rains and where there may be further protection by way of way of plastering or rendering or other finishes, the grade of mortar shall now not be much less than MM 0.7 however shall otherwise be of grade MM 2. Wherein no protection is furnished, the grade of mortar for external partitions shall not be less than MM 2. For MM2 Grade Masonry Mortars take 1 Part Cement, 2 Part of Lime and 9 part of sand (1:2:9) shown in Figure 7.

5.10 Scanning Electron Microscope Test

A scanning electron microscope (SEM) is a sort of electron microscope that produces images of a sample by scanning the surface with a cantered beam of electrons. The electrons interact with atoms in the pattern, producing numerous alerts that incorporate information approximately the surface topography and composition of the pattern. The electron beam is scanned in a raster scan pattern, and the location of the beam is mixed with the intensity of the detected signal to produce an image. In the maximum not unusual SEM mode, secondary electrons emitted by atoms excited by means of the electron beam are detected the usage of a secondary electron detector (Everhart-Thornley detector). The wide variety of secondary electrons that can be detected, and as a result the signal intensity, depends, among different things, on specimen topography. Some SEMs can gain resolutions better than 1nanometer.

Table 7. Compression test results

Block No.	No of Days	Length (mm)	Breadth (mm)	Area (mm^2)	Ultimate load (KN)	Compressive strength (Mpa)
1	28	50	50	2500	4	1.60
2	28	50	50	2500	4	1.60
3	28	50	50	2500	4	1.60

Result: The compressive strength of the masonry mortar is 1.6 Mpa referring Table 7.

Table 8. Compression strength of MM2 Grade Masonry Mortar

Block No.	No of Days	Length (mm)	Breadth (mm)	Area (mm^2)	Ultimate load (KN)	Compressive strength (Mpa)
1	28	50	50	2500	8	3.20
2	28	50	50	2500	8.2	3.28
3	28	50	50	2500	8	3.20

Result: The compressive strength of the Masonry Mortar is 3.2 Mpa referring Table 8.

IS : 2250 - 1981

TABLE 1 GRADE OF MASONRY MORTARS

(*Clauses* 0.3.1, 5.3.2 *and* 6.1)

SL No.	GRADE	MORTAR MIX (BY LOOSE VOLUME)					COMPRESSIVE STRENGTH AT 28 DAYS
		Cement	Lime	Pozzolana	Lime Pozzolana Mixture	Sand	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) N/mm²
1	MM 0·5	0	1 B or E	0	0	3	
2		0	0	0	1 (LP-7)	1·25	0·5 to 0·7
3		0	1 C or D	1	0	2	
4	MM 0·7	0	0	0	1 (LP-20)	1·5	
5		0	0	0	1 (LP-40)	2·25	
6		1	3 C or D	0	0	12	0·7 to 1·5
7		1	0	0	0	8	
8		1	0	0·4*	0	10	
9	MM 1·5	0	0	0	1 (LP-20)	1·25	
10		0	0	0	1 (LP-40)	2	
11		1	0	0	0	7	1·5 to 2
12		1	0	0·4*	0	8·75	
13		0	1A	0	0	3	
14	MM 2	0	1A	0	0	2	
15		0	1C or D	3*	0	0	
16		1	2C or D	0	0	9	2 to 3
17		0	0	0	1 (LP-20)	1	
18		0	0	0	1 (LP-40)	1·75	

Figure 7. Grade of masonry mortars as per IS: 2250-1981

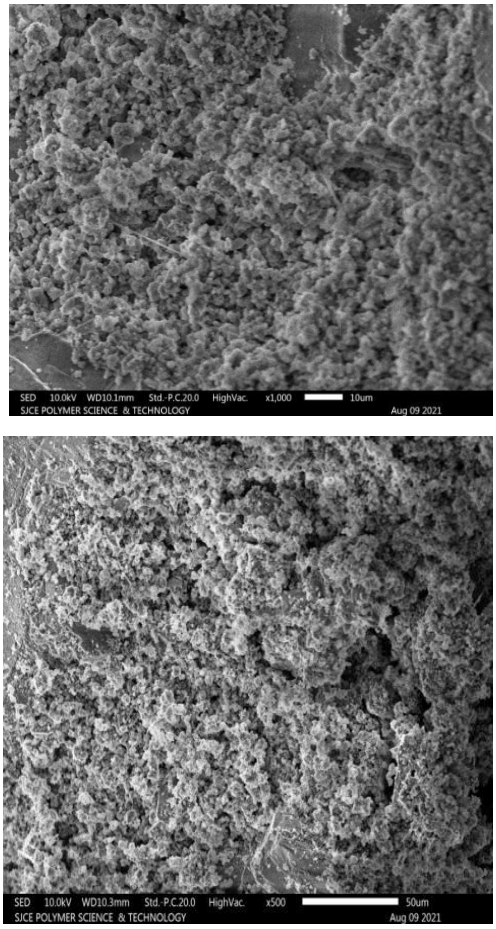


Figure 8. Lime Mortar

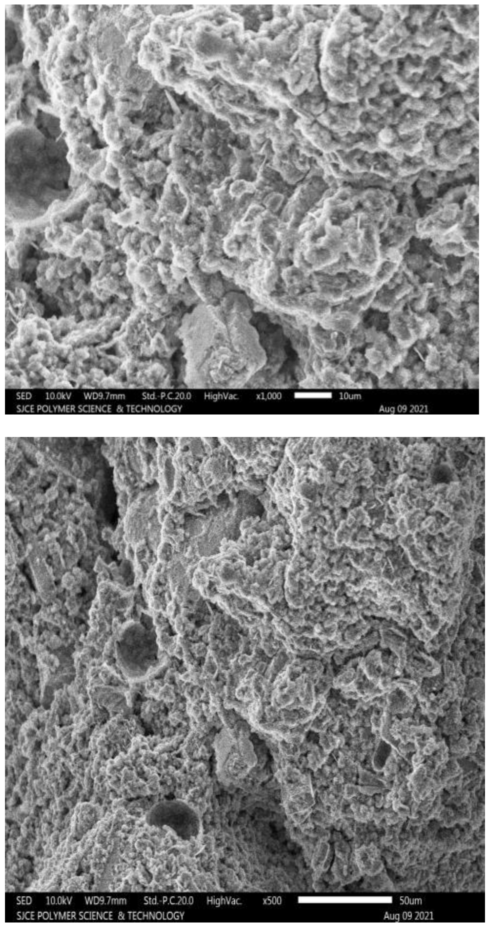


Figure 9. MM2 Grade Masonry Mortar

Result: SEM analysis shows that the mortar prepared at the site which is found with maximum voids when compare to MM2 grade masonry mortar shown in Figure 8 and Figure 9.

6. Conclusions

The following were the conclusions of the present investigation and as follows:

- The fineness, workability, initial setting time, final setting and compressive strength of lime found to be 5%, 180 mL, 1680 mints, 4320 mints and 1.46 N/mm^2 respectively.
- The specific gravity and zone of fine aggregate pertaining to 2.65 and Zone III respectively.
- The specific gravity and zone of Surkhi pertaining to 2.70 and Zone III respectively.
- The compressive strength of the jointing material used at the site was found to be 1.6 N/mm^2.
- The compressive strength of the MM2 grade masonry mortar was found to be 3.2 N/mm^2.
- SEM analysis shows that the mortar prepared at the site which is found with maximum voids when compare to MM2 grade masonry mortar.
- During the inspection of the site, it was observed that – the NDT tests on structure before and after restoration does not show any variations. Because, when we are selecting the points – we need to select on stone columns only.
- Based on the obtained test results and SEM analysis, it can be predicted that the use MM2 grade mortar will help the structure to be durable for longer period.

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Conflict of Interest

There is no conflict of interest.

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