ISSN: 2347-971X (Print)
ISSN: 2347-9728(Online)
International Journal of Innovations in Scientific and Engineering Research (IJISER)

MECHANICAL CHARACTERIZATION OF HISTORICAL MORTARS FOR RESTORATION INTERVENTIONS

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Abstract - For the preservation, repair, or restoration of heritage structures, the examination of old mortar is done. It involves the analytical study of original elements using non-destructive ways by historic structures. The most cost-effective ways to identify the constitution of historic mortars include a visual examination, color testing, cohesion testing, and microscopic inspection. A historical mortar restoration analysis (HMRA) method is proposed in this article. The paper gives findings of a study of the mechanical characteristics of cement elements produced in South Africa's greatest colonial structure, Good Hope Palace. Lime, seashell fragrances, additions, and soil mortars without binders were the original components of the palace. Thus, the mechanical nature of the underlying mortar history provides data on the sort of binders and aggregates used to restore old structures sustainably.
Keywords: Mortars, characterization, restoration, sustainability, Mechanical charactristics.

1 INTRODUCTION TO RESTORATION

Lime has been used as a binder since the second millennium BC. This kind of binder was employed to build several buildings like temples, churches, chateaux, cathedrals, memorials, and galleries [1]. Consequently, no British concrete or normal Portland concrete was built before the decade in the middle of the 18th century [2]. Instead, such buildings were built with lime or dirt mortars. Only in the middle of the nineteenth century was organic concrete brought into the construction business [3].

The studies have shown that using Portland concrete provides a negative outcome for the restoration of historical buildings and increases the degradation of the surface area of ancient masons [4]. Although buildings were erected with limestone mortars, most historical rehabilitation work continues to be carried out using portland concrete products [5].

It has been observed that the use of contemporary resources for the repair of old structures is a frequent practice. However, this technique is generally unsuccessful as lime-based mortars have different characteristics to cement-based mortars; it is thus necessary to carefully fuse the existing techniques with current Cement Concrete components [6]. Compared to Portland cement-based components with good tensile properties, less permeation, moisture heat, and potential shrinkage, lime mortars have low machinist opposition, slow setting behavior, low compressive strength, and poor flexibility stability high resistivity of freeze-thaw loops [7,8].

In most situations, the variances constitute the foundation for mismatch in the combination of the two components.

Although most historic structures endure centuries, more than some of the new buildings, over time, they are deteriorating. It is the situation with the castle since it displays evidence that its brickwork deteriorates [9]. In this case, integrity is the key issue as regards restoring the legacy. The perfectly suited restoration elements of current building elements, the characteristics of which are different from the historical originals, will be the problem [10]. The notion of the initial examination of the cultural material before restorations is not fully known.

Over the decades, constant repairs employing typically incompatible fixes might lose structural stability [11]. Furthermore, the existence of these structures is to some degree endangered by historic buildings is a serious concern. Therefore, substance analysis is recommended as a pre-restoration intervention method considering the difficulties related to the historic kitchen [12]. The assessment involves the investigation of samples of elements from structures of antiquity. It includes an on-site examination of source components and non-destructive, mild damaging, and severe laboratory testing [13]. The study might be called a reversed engineering technique to identify the basic mortar ingredients (aggregates, binders).

In this article, the physical characteristics of the components at the castle alone were examined using non-destructive tests. Details on the mortar elements were given following analyses; nevertheless, the conclusions of the physical characterization should be verified by susceptibility testing. Reliability and validity analysis may be either chemicals (type of material, hydraulicity, and concrete index for binders, type identification) or physical examination (mortar strengths).

The remaining of the article as follows: Section 2 deals with the background and literary analysis of the mortar. The proposed historical mortar restoration analysis (HMRA) method is designed and implemented in section 3. Section 4 discusses the software analysis and performance evaluation. The conclusion and findings are discussed in section 5.

2 BACKGROUND TO THE MORTAR RESTORATION

The preexisting gap in the characterization of the tile setting of mortars and contemporary procedures for their implementation are recurring and apparent in numerous research relating to the characterizing of ancient mortars [14]. The difficulties of gathering important samples may be attributed to this interval, particularly as they are beneath the settlement layer [15]. In addition, it is usual to refuse the mortar attached to the backside of the settlement during treatments, which supports a lack of examples [16]. In Portuguese, in the late nineteenth century, Fine aggregate was constructed but was cemented only in the last quarter of the twentieth century in the marketplace for brickwork. Till then, the mortar employed in the settlement was usually based on air chalk [17].

Without specific knowledge on the characterization of settlement, most experts that deal closely with preserving ancient settlement coverings are based on the few examples available in the research [18]. They are finally following the common patterns, whatever the appropriateness to the situation. Mortar employment with concrete adhesives to restore ancient settlements is a frequent excuse for lack of expertise and understanding in poorly-planned restoration treatments [19].

Their technically poor permeability and absence of water vapor permeability, or technology for their great hardness, stiffness, and deformity, are inappropriate for this sort of job, either biochemical because of its dissolved salt contents [20].

Furthermore, the crucial function of mortar in the functionality and longevity of these types of coverings has been understood in a setting where settlement heritage has been progressively effective management and restoration goals [21]. Some research has developed that appreciates the mortars' characterization but short in comparison with their significance.

Qualitative methods gathered are mostly from domestic and ecclesiastical structures, from Aveiro, Toledo, Santarém, and Évora, Portugal, from the 16th to the 20th century [22]. In general, settlement placing mortaring is validated to offer calcium lime binders, showing a dolomite lime binding with few outliers in Waitrose and Santarém [23]. However, the aggregation is mostly silicones and frequently comprises clay particles and seldom evidence.

The majority of examples are from structure façades and are thus external mortars. However, contrasted to the few indoor examples, there are no substantial distinctions that lead to the idea that the composition and application of these two types have not been distinguished [24]. More investigations could only confirm this theory.

The mean adhesive: the overall weight ratio of the case examples collected is about 1:4. The average compression hardness value is 1.69 N/mm^2, and the single value established for the ultrasonic stiffness is 1620 N/mm^2 [25, 26]. Some samples contain hydrated magnesium silicates and silicon aluminates. Sulfate, i.e., lime (calcium sulfates) and halite (sodiums more frequently from outside walls), and arcanite have been usually detected (potassium sulfates) [27].

The existence of gypsum may be attributed to many factors: the movement of the sulfate ions from the structure's interior plasters; a deliberate increase in mortar robustness or a decline in hardness; or the basic response of sulfate in the atmosphere to the calcitic mortar. The occurrence of hematite is, on either extreme, characteristic of nearby surroundings [28].

2.1 History of the Palace

The palace is the 2nd stronghold on the Cape dating back to 1667-1678. It is believed to be Southern Africa's earliest known colonial structure. This ancient structure is built out of woods, blocks construction, and has a pentagonal form [29]. The palace currently contains military components of management and organization (Headquarters of Western Cape). The building is available to visitors as well.

Like other ancient constructions, the castle worsened so much that certain portions were insecure to use. The outcome was a repair and restoration effort that began in the mid-1970s. Nevertheless, structural failure and degradation continue to occur in this structure in certain locations. Natural causes like age and corrosion are responsible for some of the degradation [30].

Moreover, not just for this construction but also for many other historic structures across the globe, the current usage of unsuitable resources to restore ancient sections looks to be a difficulty. The study addressed this worrisome problem generated by the frequent practice of using unsuitable resources in the renovation of historic structures.

3 PROPOSED HISTORICAL MORTAR RESTORATION ANALYSIS (HMRA) METHOD

The specimens were gathered and brought to the research lab to examine Block B - an old kitchenette. A comprehensive visual examination on site was conducted before laboratory analysis. The examination examined features of the utilized mortar, such as degradation and surface component quality (original or repairing).

3.1 Materials

For examination with a tiny hammer and chisel, nine typical specimens were obtained. In addition, the flooring, plaster, and mattress materials were gathered when feasible by 1 kilogram. Affected areas were those previously harmed to prevent the architecture from being disturbed. In line with the collecting database, all specimens were identified and characterized by their appearances in color, structure, and position.
The data table displays information such as the position of the specimen (wall, base, exterior, or interiors), which includes either rendering, plastering, or joining/bedding functions.

Figure 1 Collected samples for the analysis

Fig. 1 illustrates the collected samples for the analysis and some of the collecting samples before the mechanical examination, and the components created awaiting examination. The specimens were made for further examination by gently smashing using a crusher and pestle after extracting intact components as described above. It must have been done so that the corresponding particle dimensions of aggregation that could influence the gradient curve could not be broken.

Discrete stages are taken in the approach presented. The assessment of the framework in reference of specific pressures, perseverance of the system fault zones, and the corresponding damage rates, both concerning the method in its current conditions and are included in general in the assessment or perseverance of structural characteristics of components projection of the architectural framework and force.

Lastly, fragility curves are constructed based on the indicators of damages, which help evaluate the building's susceptibility under the present conditions quantitatively and the efficiency of the various repair possibilities.

3.2 Workflow

The following eight different phases are covered in the suggested approach, which also determines the organization of the current study.

Fig. 2 shows the flowchart of the proposed HMRA model. It has eight stages, and it is explained below:

Stage 1: Structural reliable rebuilding

Current masonry models are a precondition for an accurate seismic susceptibility evaluation and the right decision-making procedure throughout a recovery procedure. For this purpose, precise data must describe the complete structural geometry and its topology and mechanical properties. In addition, theoretical restoration is essential to incorporate material linkages. Such interconnections should be extensively studied in horizontal walls or wooden floors.

Stage 2: Assessment of materials and physical features

The characterization of the construction elements is one of the key challenges for the functional modeling of masonry buildings. In addition, both the characterization and characteristics of elements like rocks, brickwork and mortars are essential to the physical modeling of the building in monumental maceration constructions. When working with ancient steelworks, the investigator has to bear in mind that both the building and the elements it contains are disrupted systems that have been used for many decades or perhaps even centuries under actual physical and atmospheric stresses.

The historic construction materials and their features are a reflection of the used material. Therefore, the characterization and prognosis of cultural components are vital for obtaining the data required for assessing the reaction of the memorial in its present state, as well as selecting new interoperable and pertinent reconstruction materials which serve sufficiently concerning the physical stresses which it has to face and which are sustainable concerning environmental.

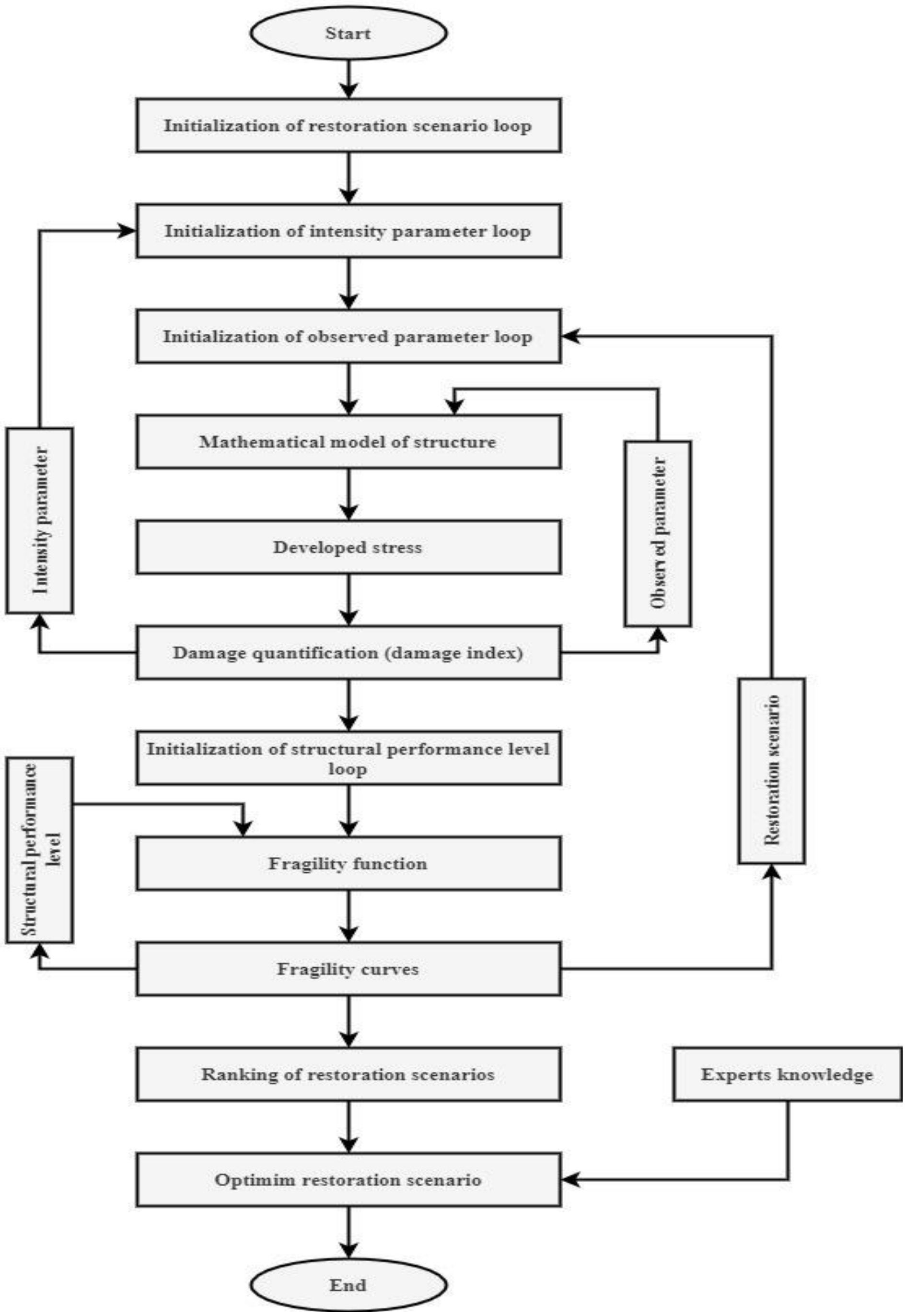

Figure 2 Flowchart of the proposed HMRA model

Stage 3: Model of the structure

It is a complex and challenging undertaking for engineers to choose and utilize the best mathematical model for the mechanical modeling of brick constructions. Additionally, structural modeling is essential for accurate structural modeling and significant importance to architects in complicated historical buildings comprising numerous elements. In light of the preceding, the next part contains a state-of-the-art study on the systemic modeling of structural elements. Furthermore, a novel asymmetrical macro-model of finite elements was also created and described in depth in one part.

Stage 4: Actions

Various loading scenarios, particularly seismic activities for structures constructed in seismic regions, have to be addressed. Slow loadings, live loadings, and requirements for earthquakes must be combined. Earthquakes must be taken into account in any adverse way for the construction. However, several problems remain open, e.g., the weak hysterical performance of the maceration or the unfavorable effect on the seismic effect's concurrent vertical element.

Stage 5: Analysis

The final element assessment is done using data from the initial phases, and loads (normal shaving) – deformations at the mesh joints – are computed. Because of their real activity and the high level of self in the initial phases, elastic modeling is an initial valued tool for these constructions, particularly during repair and reinforcements.

Stage 6: Criterion for failing and evaluation

Failing criteria must be defined for defining the failed structural areas (as first insights). Considering the results of stage 2 regarding the properties of the substances, a criterion of this kind is suggested and utilized to analyze it. The outcomes of this failure are utilized to create a damaged indicator as inputs. Based on this indicator, the structure's potential is assessed for construction to be harmed at various accelerations over a specific threshold (severe, medium, and negligible). This knowledge is crucial for a heritage structure throughout the assessment and re-designs procedure, as it allows the model to examine several situations with alternative repair/fortification choices.

Stage 7: Reparation and reinforcement of decisions and review

All damaged areas are fixed and reinforced following the findings of Stages 5 and 6. The approach to be employed can be linked directly to the outcomes by the size of the treatment, the type of substance, etc., depending on semi-metric formulations for the final physical properties of masonry. The final components, loads, and structural information must be included in a new architectural evaluation. The assessment findings are later used in the Stages 5 and 6 procedures. The choice for restoration or reinforcement of the existing building has been approved (or rejected) in the final assessment.

Stage 8: Report on Explanation

The last phase, as a consequence of the approach presented, is comprehensive. Explanation report contains all the information gathered, the diagnoses and the security assessment, and any choice to act. Therefore, this paper is crucial for upcoming analyses and structural adjustments.

3.3 Methods for Analysis

There are four methods available for the identification of the materials gathered, and it is explained below.

3.3.1 Visual Inquiry

Visual inquirywas performed following a specified technique. The mechanical technique of analysis differentiates between the initial and the current repair materials. This characterization approach assesses the behavior of the two parts from various eras. Components are evaluated on-site for laboratories sample before collection. At this point, it is expected that the materials, binders, and aggregate kinds will vary in color. It provides the necessary information to reject the usage of any inconsistent content at the moment.

3.3.2 Cohesion Test

The material's structure was evaluated. This process includes using hands and fingers to rubbed and broken between the fingers to identify its type. This analysis approach helps to determine the roughness of the aggregate utilized for material manufacturing. No hardware or instrument is required for the technology. The ruggedness of the specimen reflects the strong aggregates concentration in the mortar, and the smooth mortar surface shows the high concentration of the binders.

3.3.3 Microscope Assessment

The mortar is put under an imaging microscope to evaluate the particulate and particle dispersion. The size of the component particles is established using this characterization approach to guide the treatment for replica restoration components. The tiny pictures show the sample features that the human eye ignored.

3.3.4 Sieve Assessment

The test was performed to evaluate the dispersion of particle size. The composition of a mortar mix is essential. While their characteristics do not depend on their gradations, the soil's arrangement into a mortar mixing influences its architectural qualities. The distribution structure is therefore deemed necessary. Only structural samples larger than 300g can be considered. Because of the employment of a vast quantity of materials, particles in all sizes of seven have the best depiction.

This investigation was conducted using the non-standard dry technique. It means that 300 g of mortar in powder form is passed through a series of sieves and weighed on each seal. The exponential plot of particulate dispersion curves calculated the useful variables for soil. Variables include the homogenous (C_u) and curving (C_c) coefficients, which are calculated by extrapolating the appropriate seven-size substance from the extrapolating of the 10%, 30%, and 60%.

- Homogeneity coefficient

The homogeneity coefficient is a metric that assesses the constancy of the particle sizes, and it is expressed in Equation (1).

$$C_u = \frac{D_{(60)}}{D_{(10)}} \quad (1)$$

The sieve length when ten percentage of the particulates and 60 percentage of the particulate are denoted as $D_{(10)}$ and $D_{(60)}$.

- Curves coefficient

Curves coefficient (C_c) assesses the fluctuation of soil particulate size and thus the grading of various particle size categories. The calculation is based on Equation (2). The C_u of 1 shows the same particle sizes (low graded matter), the $C_u > 1$ implies that the substance is uniform. The conditions must be met to classify the soil: $C_u > 1 < C_c < 3$. The curves coefficient is expressed in Equation (2)

$$C_c = \frac{{D_{(30)}}^2}{D_{(10)} \times D_{(60)}} \quad (2)$$

$D_{(10)}$ – the length of the sieve when 10 percent of the particulates remain intact.

$D_{(30)}$– the length of the sieve when 30% of the grains are still contained

$D_{(60)}$ – the length of the sieve when 60% of the grains remain in use

4 SOFTWARE ANALYSIS AND PERFORMANCE EVALUATION

The research was conducted at Cape City, West Cape Region, Africa. The castle was once erected on the shores of Moreton Bay but is now inland because of rehabilitation. The materials are gathered and manually examined in the kitchens (the oldest section of the palace). The majority of the collected specimen is in whitish and yellow color. The collected samples are named based on their color as 1 to 9. The ten samples are analyzed, and the results are shown below.

Table 1 Passing percentage analysis of the samples

ID/ Sieve size	0.1 mm	1 mm	10 mm
1	8.1	92	98
2	6.8	86	97
3	9.2	73	98
4	7.2	64	96
5	7.6	54	94
6	9.6	82	97
7	8.9	49	98
8	7.2	65	95
9	10.1	72	97

Table 1 shows the passing percentage analysis of the samples. The collected ten samples are analyzed using the proposed model with the size varies from 0.1mm, 1mm, and 10mm. The final predicting result is compared with the reference specimen, and the percentage of similarity to the reference is calculated and tabulated in the above table. The results indicate that as the particle size increases, the classification accuracy also increases.

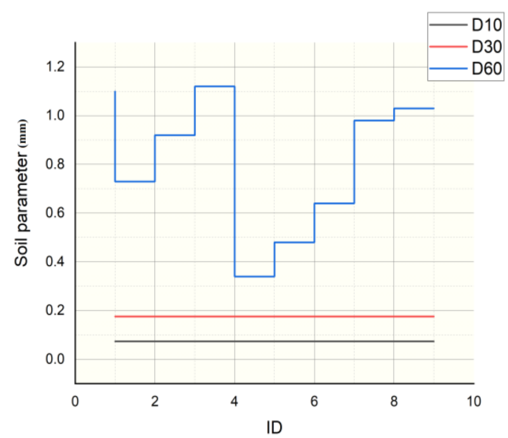

Figure 3 Soil parameter analysis

Fig. 3 shows the soil parameter analysis of the gathered ten samples. The specimen parameters are calculated using the proposed model, and the soil parameter is measured and plotted in the above figures. The soil parameter for the smaller specimen is the same for all samples, and when the sample size is 60% of the grain size, the soil parameter is easily identified. The proposed model accurately finds the samples and their characteristics.

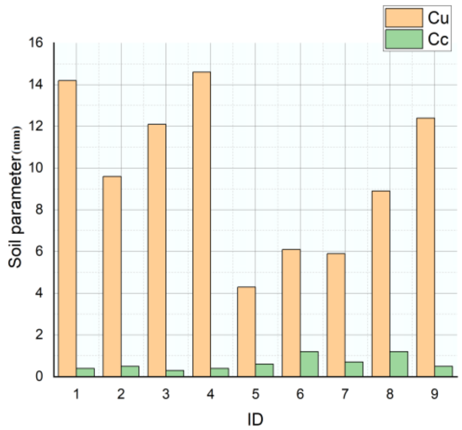

Figure 4 Soil parameter curvature analysis

Fig. 4 shows the soil parameter curvature analysis of the proposed HMRA model. The curvature of the curvature coefficient and the homogeneity coefficient of the ten samples are analyzed, and the result is plotted in the above figure. The results indicate that the proposed model accurately finds the curving coefficient and homogeneity coefficient. The curving parameter has the lowest value than the homogeneity value.

The proposed HMRA model is analyzed using the ten samples taken from the palace in Africa. The simulation outcomes such as soil parameters like the curvature coefficient and the homogeneity coefficient, particle size, passing percentage of classification are analyzed and plotted. The results indicate that the proposed model has the highest efficiency and accuracy for all the samples and all sizes of the particles.

5 CONCLUSION AND FINDINGS

Before any repair of the historic structures is carried out, it is important to research and comprehend the physical qualities of the original mortars. It offers precious information on the structure of materials as a guideline for the research for replicate components. In the African region, the idea of historical material features has still to be studied in depth. Only a few research have examined the characteristics of historical properties of materials in Africa for rehabilitation work.

A historical mortar restoration analysis (HMRA) method is proposed in this article. To offer comprehensive data on mortar compositions, thus the consistent restructuring, examining the architectural and the chemical, geological and structural characteristics of historical mortars would be. Furthermore, the research in that region would be a worthwhile expenditure since its suitable and ecological repair will enhance the life duration of historic structures. The proposed model shows higher accuracy and efficiency in predicting the physical characteristics of the particles.

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