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Structural Damage Diagnosis and Rehabilitation Using Fuzzy Information

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Abstract: Disaster mitigation and rehabilitation are becoming increasingly important due to variety of natural and man-made disasters and due to ageing of many of the systems in place over several years. One of the major components of mitigation and rehabilitation is the human angle which forms the basis of follow-up action and this comes from the many physical visits and visual perception each has on the quality of the disaster. This study presents the results of visual and oral communication formats used by different strata of people-politicians to engineers-visiting the site and the implication in terms of assessment of damage and possible rehabilitation, based on engineering modeling and analysis. Based on this, it may be seen that rehabilitation measures could vary significantly, depending on the vagueness and interpretation of visual data.

Key words: Damage, rehabilitation, fuzzy logic, MATLAB

INTRODUCTION

All civil engineering structures are initially designed depending on certain design criteria such as design loads, stresses and so on. But damage due to an extreme event is always possible in a structure during its design life. A well-designed structure may survive a damaging event but its safety cannot be guaranteed, depending on the initial design parameters. Sometimes undetected and unrepaired damage may lead to structural failure demanding costly repair and a huge loss of lives. Therefore, the problem of maintenance, repair and rehabilitation of existing civil engineering structures involves damage detection at an early stage. For massive structures such as bridges and dams constructed some 50-60 years ago, it is necessary to test their functionality under the present load situation and quantify damage, if any, to rehabilitate and enhance their performance, since demolishing and reconstructing them would involve huge investments. Evaluating the reduction in performance is normally done through stiffness, defined as load per unit deflection and this in turn will allow an estimation of remaining load carrying capacity of these structures, which is very important for assessment for rehabilitation. Repair and rehabilitation projects, often involve handling of uncertain and vague information. Fuzzy theories (Zadeh, 1975; Mamdani, 1977; Dubois and Prade, 1980) can be used to model and design such projects involving vague and imprecise information by having transition stage from absolute precision to absolute imprecision (Castaneda and Brown, 1994; Zhao and Chen, 2002; Jincai and Yang, 2004; Rao *et al*., 2006; Kim *et al*., 2007).

The basis of the study presented in this study, relates to some typical cases using fuzzy information processing and consequent engineering model, to assess damage levels and suggest rehabilitation measures, within a short period of time. It is hoped that this approach will be effective in online internet cellular communications. Since the base inputs are regular English words, the diagnostics and rehabilitation also are given in literal terms so that implementation will be easier and faster.

VISUAL AND ORAL INFORMATION BASES

The disaster effects on infra structural systems are normally looked at qualitatively and the inputs are literal English words commonly understood by all. Figure 1 shows the images of two systems which can be described in literal terms as severely damaged or in short form SD. But if one looks at the pictures, another description could be highly damaged or in short HD. But the assessment of cases in Fig. 2 could be more ambiguous as both moderately damaged to highly damaged can be given as oral communication about the damages and this depends on the engineering background of the inspector as well.

But the importance of these visual or oral data is to be seen from the point of view of assessment of damage, monetary investment to restore the structure, time and technology needed for rehabilitation. Hence it is proposed to study these literal inputs with the use of fuzzy representation with membership functions (Zadeh, 1965; Kosko, 1997; Sundareswaran, 2005) and later use engineering modeling for quantifying analytical properties

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Fig. 1: Examples of cases -Severely damaged-SD

Fig. 2: Example of cases -Moderately damaged -MD

to enable the evaluation of responses. These responses are later converted to literal indices and based on these; the types of rehabilitation needed are identified.

MODELING ISSUES

Damage assessment and rehabilitation process can be modeled using fuzzy representation for input data which may be in visual or literal forma-and later using numeric representation as inputs, regular engineering modeling through domain dependent finite element formulation is done to analyze the responses and these responses are later converted to literal ones which will be used to identify the types of rehabilitation. A schematic flow diagram is shown in Fig. 3. The fuzzy representation is done by membership functions and FEM is done based on a code developed at National Institute of technology (Dinesh, 2006; Revathy, 2007). In this study results on oral communication and components of systems like beams are presented. The visual part is presented elsewhere (Fatima *et al.*, 2007).

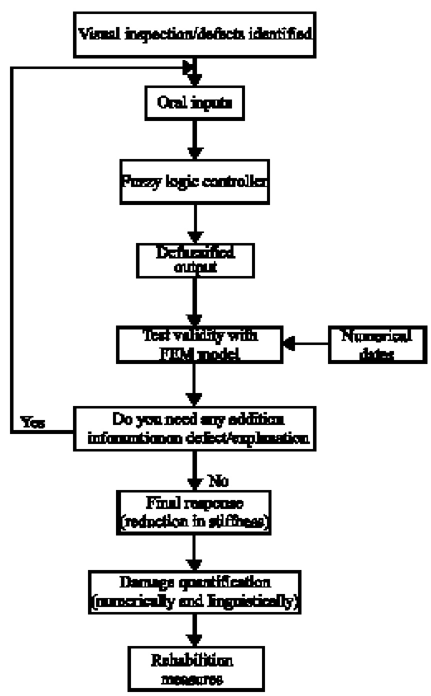


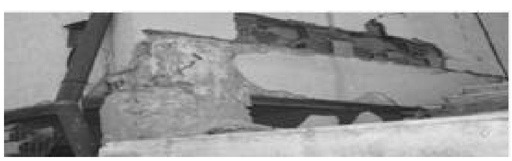
Fig. 3: Flow diagram for modeling the process

CASE STUDIES

The case studies chosen here are components in building affected by disasters and oral assessments are obtained based on news headlines, visits by non-engineers and engineers.

Normally the oral inputs combine location and spread as shown in Fig. 4. Here the damaged beam is shown and the forms of literal data obtained are indicated. One can see clearly the ambiguity of the representation of the status and this is where fuzzy information processing helps. Now the English terms used by news, non-engineer and engineers are given by representations as given in Fig. 4 for the three parameters. For example LS and SD represent left support for location and spread and severely damaged for intensity of damage. Now the purpose of analysis and modeling is to give an indication on the status of damage and methods of rehabilitation. The equivalent finite element model could be as shown in Fig. 5 where three parameters A1, A2 and A3 define location, spread and intensity as shown.

The damage parameters are represented by membership functions with one for combined location and spread and another for intensity. Using these, finite element model analysis could be done for several cases with varying values of intensity of damage reflected as material property. For a typical case, the analysis results could be given in terms of deflection changes and stiffness variation. This is shown in Fig. 6 (a) shows the effect on deflection response of the beam. Here location



(A) Visual information

A. Left support-severly damage-LS and SD
B. Left one third- fairly damage-L3 and FD

(B) Oral interpretation

Fig. 4: Information-damaged beam

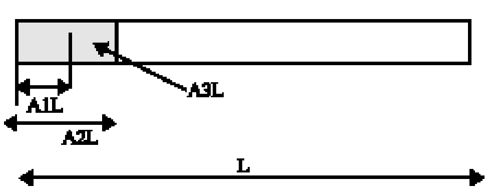


Fig. 5: Beam model for analysis

and intensity are taken as base parameters and deflection variation is shown normalized with the span. It may be seen that deflection increase could be as high as 4.5×10^{-3} for the damage intensity of 95%, located at the centre of the beam.

Based on deflection and load, the overall stiffness of the beam and its variation are shown in Fig. 6 (b). Here the system performance is obtained. Now using these numerical inputs, reverse fuzzy processing could be done to give literal interpretation as ‘light reduction’ or ‘moderate reduction’ so that its effect on rehabilitation could be used. A code based on this was developed and applied to some actual building components which got distressed or damaged due to different calamities and disasters. Few of the results will now be presented for appreciation.

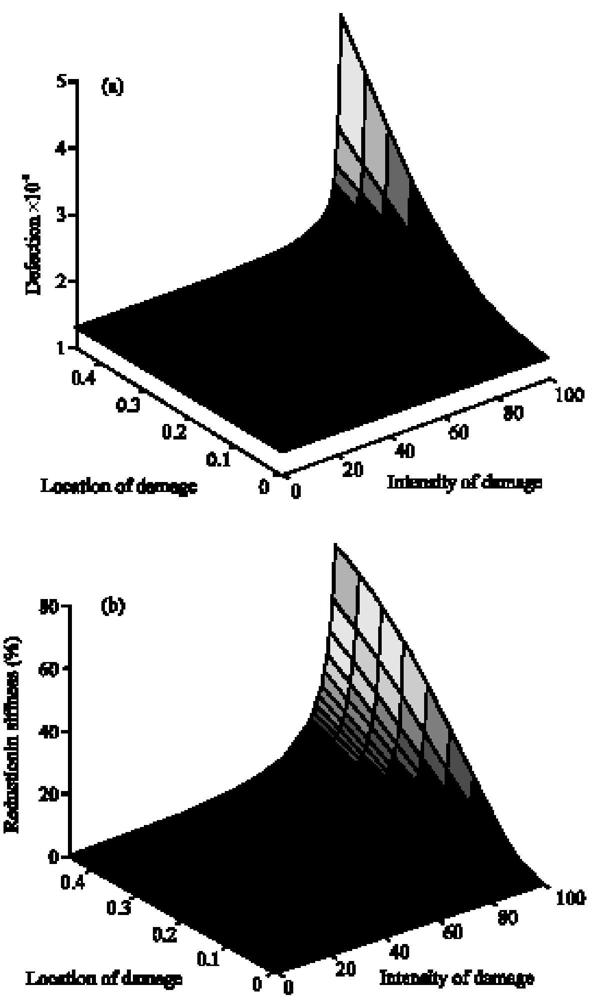


Fig. 6 (a): Deflection response (b) Stiffness degradation due to damage

Figure 7 shows visual images of some damaged beams and these indicate that the three parameters viz., location, spread and intensity are very difficult to be interpreted numerically. A different dimension of difficulty arises when the oral interpretation, observed by different groups of persons visiting the site and here some of this literal data in non-numerical form are taken and the oral communication status is given in tabular form. The terms 'severe', 'moderate', 'high' are suitably converted to membership functions so that an equivalent numerical data is obtained. These are shown in Table 1. Now, with the numerical model, detailed analysis is carried out to assess the responses in terms of deflections at critical points-forces are not taken-and system performance in terms of stiffness changes is obtained. These are later suitably interpreted in terms of qualifiable statements and rehabilitation methods are suggested.

Fig. 7: Visual data of some damaged beams

Table 1: Typical result for rehabilitation

A. Location	B. Intesity	C. Stiffness reduction Numerical	Fuzzy	D. Rehbilitaion
Left support	NMD- SD	0.355	NMR	None
	VSD	4.62	MR	Llocal surface
Left one third	NMD- HD	0.355	NMR	None
	SD	4.97	MR	Local surface
	VSD	16	FR	Local surface
Middle one third	NMD- NSD	0.355	NMR	None
	FD-HD	4.97	MR	Local surface
	SD	16	FR	Local surface
	VSD	27.3	HR	Global surface
Near to centre	NMD	0.355	NMR	None
	NSD	4.97	MR	Local surface
	FD-HD	16.3	FR	Llocal surface
	SD	27	HR	Global surface
	VSD	45.8	VHR	Global surface
At the centre	NMD	0.355	NMR	None
	NSD	4.97	MR	Local surface
	FD	16.3	FR	Local surface
	HD	27	HR	Global surface
	SD	46.5	VHR	Global surface
	VSD	70	SR	Failed

Rehabilitation; Local surface-plastering to rectify local surface cracks; Local structure-strengthening portion of distressed beam; Global surface-plastering/guniting entire beam surface ; Global structure-strengthening entire beam

In Table 1 for the case of 'severe damage-SD' at 'centre', stiffness degradation could be as high as 46.5% and this might need rehabilitation for the entire beam termed as 'global structure'. The type of rehabilitation presented in Table 1 fall under surface treatment for minor cracks to modifying the complete beam with increase in size and additional reinforcements.

CONCLUSION

The main focus of the study is on the effect of oral communication on disaster affected areas based on different types of visitors and their effect on methods for rehabilitation for speedy recovery. This approach will be very effective in internet and cable-based networks with computer nodes providing the necessary measures on-line based on oral inputs so that recovery is immediate and effective.

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