Structural Analysis of Historic Construction – D'Ayala & Fodde (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-46872-5

Non destructive and laboratory evaluation of strength of decayed wood members in a historic construction located in Gorgan (North of Iran)

M. Madhoushi
Department of Wood & Paper Sci. and Indus., Gorgan Uni. of Agri. Sci. & Nat. Res., Gorgan, Iran

J. Eimanian
Iranian Cultural Heritage Organization, Gloestan Head Office, Gorgan, Iran

M.P. Ansell
Department of Mechanical Engineering, University of Bath, Bath, UK

ABSTRACT: The House of Bagheri is one of the most important buildings in Gorgan city (North of Iran) which is a tourist site and the House is a Cultural Heritage Construction. Solid wood was utilized extensively for structural members in association with other traditional materials. It has been exposed to natural environmental conditions for a long time, so some faults have developed including decay of the wooden members. The mechanical properties of decayed members have been measured in laboratory tests and the buildings have been non-destructively evaluated. Samples from the buildings were prepared which are representative of the whole structure. Flexure and compression tests were then performed on these samples. The results of NDE (nondestructive evaluation) tests on the samples were correlated with those on the buildings.

1 INTRODUCTION

Gorgan is located in the North of Iran between the Caspian sea and the Alborz mountains where the climate is mostly Mediterranean (with average rainfall of 432.1 mm and RH between 62.5% and 74%). It is considered to be a heritage city because of its history and historic buildings some of which contain solid wood structural elements.

This paper evaluates the structural integrity of one of the most important historic building in Gorgan, called the House of Bagheri which is a tourist site and is designated as a Cultural Heritage Construction. The strength of decayed wood members is measured by using both a nondestructive stress wave method and a static laboratory measurement to quantify mechanical properties.

The House was built approximately 150 years ago with a floor area of 3000 m^2 (Eimanian, 2001) and is now under repair. Solid wood was utilized extensively for structural members including beams, columns, rafters, roofs and floors in association with other traditional materials i.e. brick and cob (a mixture of clay and straw). Doors and windows are completely wooden and are well preserved. Due to long exposure to the natural environment, some faults have developed including decay of wooden members.

Figure 1. A view of the House of Bagheri.

The building is a collection of several main parts and yards. A small pool is located in the centre of each yard surrounded by buildings. Although there is a one-storey building in this complex, it is mainly built on two-stories with a few steps between floors (Fig. 1). The buildings have nearly the same architectural characteristics and the plan of one building is shown in Figure 2.

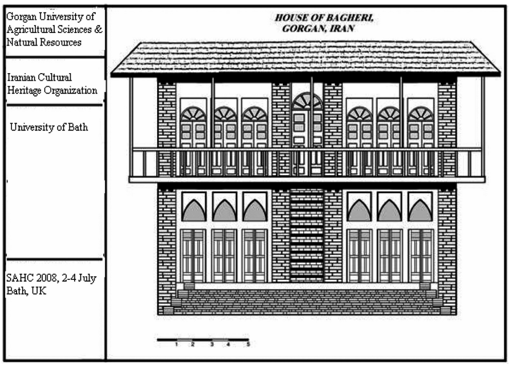

Figure 2. A plan of one building of the House of Bagheri.

Figure 3. Measuring the transmission time of stress waves.

This building possesses a rectangular structure and used construction materials which were essentially brick and cob in the shear walls and solid wood in the principal structural elements. Its main defects have been previously reported by Madhoushi & Eimanian (in press). Degradation caused by weathering (sunlight and rainwater splashing), decay and insect attack have led to damage and faults in the building. It is now under repair and most defective structural elements have been substituted by new members.

Today, repair and restoration of historic buildings is a major challenge for society (Lourenco et al. 2006). The conservation and repair of these mostly timber buildings is important due to the unique response of timber structural members under seismic loading (Ceccotti et al. 2006, Tampone & Messeri 2006). Previous studies conducted on historic wood buildings showed that moisture and fungal decay could be considered as the main source of damage (Ronca & Gubana 1998, Pasanen et al. 2000). However, it was shown by Madhoushi & Eimainan (in press) that in the House of Bagheri, insect and weathering damage as well as fungal decay are the source of degradation.

The stress wave technique is one of the methods used widely for the inspection of load-bearing timber members. Previous studies (Haines et al. 1996, Machek et al. 2004) show that there are good relationships between static MOE (Modulus of Elasticity) and dynamic MOE. These relationships depend on species, grain direction and existence of defects.

The fundamentals of the stress wave method and its applications have been explained by Pellerin & Ross (2002). This method can be applied in the evaluation of members in timber structures (Ross & Pellerin 1994) and decayed wood (Ross et al. 1996). A previous investigation (Madhoushi et al. 2006) showed that this method might be used for assessing the decay of Iranian hardwoods and it was suggested as an *in situ* evaluation technique for decayed wooden members of historic structures.

2 MATERIALS AND METHODS

A nondestructive study was conducted using an IML® electronic hammer in order to produce stress waves in wooden members. Eight accessible structural elements were selected as representative of the whole structures (since the building is under repair, access to most of elements was not possible) and the transmission time of the stress waves were measured at three point on each sample in order to define the area of decay (Fig. 3). At each point, the instrument provides three readings.

It should be noted that there was not any intention to replace these elements with solid wood. Eight samples were removed from the structure and selected as representative of the whole building. They were subjected to static laboratory experiments to measure their mechanical properties including flexure and compressive properties parallel to grain. Finally, the data were analyzed and compared with the NDT (nondestructive testing) data.

3 RESULTS AND DISCUSSION

3.1 *Nondestructive evaluation*

The measured transmission time of stress waves indicates (Table 1) that 50% of samples are totally decayed and that 12.5% of samples are slightly decayed. Only about 25% of the samples can be considered as sound or nearly sound. Finally, 12.5% of samples are extensively decayed and distorted and contain fractures so that they cannot be reused. These samples are termed "unusable".

It is clear that the building is not in good condition and its repair is necessary. Although some parts have been renewed without NDT inspection it seems these parts are solid. In contrast, some parts are in their

Table 1. The measured transmission time of samples and their condition.

No	Transmission time (μs) 1*	2	3	Baseline (μs)	Condition
1-h**	333	357	341	650	TD***
1-s	863	829	888	143	TD
2-s	634	678	618	158	TD
3-h	567	599	584	650	SD
4-h	3891	4587	3125	52	UU
5-h	432	489	473	585	NS
6-s	364	313	403	520	S
7-s	741	783	718	156	TD
8-s	282	311	272	234	SD

* Place of measurements on sample.
** h for hardwood, s for softwood.
***TD: total decayed, SD: slight decayed, UU: unusable, NS: nearly sound, S: sound.

Table 2. The mechanical properties of old wood members measured in laboratory.

Sample	Condition* 1	2	MOR (MPa)	MOE (GPa)	E in $C_{\|\|}$ **(GPa)
Rafter 1	NS	SD	79.12	10.46	3.16
Rafter 2	S	SD	88.73	8.9	3.43
Column 1	S	TD	***	***	2.44
Column 2	NS	TD	***	***	3.35
Door Frame 1	NS	S	79.77	9.09	10.2
Door Frame 2	TD	TD	12.67	2.12	2.15
Beam 1	TD	TD	22.56	3.48	2.58
Beam 2	NS	S	74.8	9.15	10.68

* Evaluated (1) visually by expert carpenter based on experience, (2) after examination.
** Modulus of elasticity in compression parallel to grain.
***was not measured.

original condition without any repair or treatment, and they are not in a good condition.

3.2 *Static mechanical properties*

The static mechanical properties measured in the laboratory show (Table 2) that some elements do not possess acceptable strength in spite of the visual evaluation to the contrary. For example samples from Rafter 1 were considered to be nearly sound elements, whereas in fact the MOR (Modulus of Rupture or bending strength) and MOE and the modulus of elasticity in compression parallel to grain (E in $C_{||}$) have all been reduced by decay. In contrast, Door Frame 1 is sound and has acceptable mechanical properties in spite of its grading as nearly sound. It is clear that visual evaluation, even by an expert carpenter, is not accurate and using NDE methods is advised in this type of investigation. Table 3 proves that there is a difference between visual inspection and scientific examination.

Table 3. Comparison between stress wave NDT, laboratory examination and visual inspection.

	TD	SD	UU	NS	S
Stress wave NDT	50	12.5	12.5	12.5	12.5
Lab Examination	50	25	–	–	25
Visual Inspection	25	–	–	50	25

3.3 *Comparison of the data*

A comparison of the data is shown in Table 3. There were not any unusable samples in laboratory examination and visual inspection, because they wouldn't be used again in restoration of the building. It can be seen that if we ignore the unusable samples tested using NDT, both the stress wave NDT and lab examination results are very close to each other. Both methods show that 50% of the samples are totally decayed and 25% of samples are nearly sound. However, it is more difficult to distinguish the slightly decayed by laboratory examination and these results depend on the extent of decay. This outcome is discussed in more detail by Madhoushi et al. (2006). Visual inspection based on personal experience produces is inherently variable and results are not to be trusted.

In general, since there is good accordance between the results of stress wave analysis and laboratory test results, both methods can be used to assess the integrity of timber during repair and restoration activities. However, NDT is a more economic and cost-effective method.

4 CONCLUSIONS

- The House of Bagheri is a heritage wood construction building in Gorgan in which the timber members contain some damage and decay.
- Stress wave nondestructive method has been used in the evaluation of the building and it showed that 50% of the structural elements tested are totally decayed and decay is initiated in 25% of the structural elements tested.
- Laboratory testing demonstrated that some old members are not of acceptable strength in spite of their good appearance and visual inspection.
- As much of the building as possible will be retained for restoration.
- There is good correspondence between stress wave nondestructive evaluation and laboratory mechanical tests.
- It is advised that the NDT method should be used in association with visual inspections in the assessment of this heritage building.

REFERENCES

Ceccotti, A., Faccio, P., Nart, M., Samghaas, C. and Simeone, P. 2006. Seismic behaviour of historic timber frame buildings. *ICOMOS Intern. Wood Committee; Proc. 15th intern. Symp., Istanbul and Rize, 18–23 September 2006*.

Eimanian, J. 2001. *Restoration suggestions on House of Bagheri'*, MSc, Thesis, Islamic Azad University.

Haines, D.W., Leban, J.M. & Herbe, Ch. 1996: Determination of Young's modulus for spruce, fir and isotropic materials by the resonance flexure method with comparisons to static flexure and other dynamic methods. *Wood Science and Technology* 30 (4):253–263.

Lourenco, P.B., Luso E. & Almeida, M.G. 2006. Defects and moisture problems in buildings from historical city centres: a case study in Portugal. *Building and Environment* 41 (2): 223–234.

Machek, L., Edlund, M., Sierra Alvarez, R. & Militz, H. 2004. A non-destructive approach for assessing decay in preservative treated wood.*Wood Science and Technology* 37 (5):411–417.

Madhoushi, M., Ansell, M.P. & Hashemi, M. 2006. Application of NDT stress wave method for assessing property changes in decayed wood of Iranian beech *(Fagus orientalis)*. Integrated Approach to Wood Structure, Behaviour and Applications; *Proc. ESWM and COST Action E35 meeting, Florence, 14–17 May, 2006.*

Madhoushi, M. & Eimainan, J. (in press). Faults and Repairs in House of Bagheri: A Cultural Heritage Construction in Gorgan (North of Iran) – A Case Study. *Submitted to 11DBMC Inter. Conf. on Durability of Building Materials and Components, Istanbul, 11–14 May, 2008.*

Pasanen, A.L., Kasanena J.P., Rautialaa S., Ikaheimoa M., Rantamakib, J., Kaariainenb H. & Kalliokoskia, P. 2000. Fungal growth and survival in building materials under fluctuating moisture and temperature conditions. *International Biodeterioration & Biodegradation* 46 (2): 117–127.

Pellerin, R.F. & Ross, R.J. 2002. Inspection of timber structures using stress wave timing non-destructive evaluation tools. In R.F. Pellerin & R.J. Ross (eds), *Nondestructive Evaluation of Wood*: 135–148. Forest Products Society.

Ronca, P. & Gubana, A. 1998. Mechanical characterisation of wooden structures by means of an *in situ* penetration test. *Construction and Building Materials* 12 (4): 233–243.

Ross, R.J. & Pellerin, R.F. 1994. Non-destructive testing for assessing structures: A review. *Gen. Tech. Rep. FPL-GTR-70 (Rev.)*. Madison, WI, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 40 p.

Ross, R.J., De Groot, R.C., Nelson W.J. & Lebow, P.K. 1996. Assessment of the strength of biologically degraded wood by stress wave NDE. In C. Sjostrom (ed.), *Durability of Building Materials and Components* 7 (V1): 637–644. E & FN Spon.

Tampone, G. & Messeri, B. 2006. Compliance of the practice of strengthening ancient timber structure in seismic areas with the official documents on conservation. *ICOMOS intern. wood committee, Proc. 15th intern. Symp., Istanbul and Rize, 18–23 September 2006*.