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Study on field survey methods of architectural heritage dampness symptoms of timber material

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ABSTRACT

Dampness of materials is a vital factor in affecting the secure conservation of architectural heritage. Environment with overmuch dampness may cause the erosion of material and accelerate its damage. Pathological symptoms caused by materials can be seen everywhere in architectural heritage. Therefore, in the first stage of field survey in heritage restoration, investigation on pathological symptoms of material dampness is one of the most important aspects.This study evaluates the field survey of timber material quantitatively and qualitatively from the building pathology. Moreover, according to the differentfeatures of moisture contentin timber material, this study also provides some fundamental methods in diagnosing the extent of erosion and destruction of material, and thus can be taken as reference when applying the method of field survey to practice in spot in the future.

KEYWORDS

Building pathology;
Building dampness symptoms;
Field survey methods;
Architectural heritage;
Timber material.

INTRODUCTION

Building dampness damage is supposed to be one of the threats to safe preservation of architectural heritage in hot-humid environment. Dampness damage can not only cause the corrosion, strength reduction and color changes of materials, but also have microorganisms inserting on it which would affect the health environment and cause a negative visual impact.

Generally, diagnosis survey of the architectural heritage and harm status of the materials should be conducted before the restoration. A regular way taken as a field survey method of material damage symptoms of the ancient buildings is "Check-list Method"[1]. This method can only make a subjective judgment of the surface phenomenon of the material, which results in deviation caused by different researchers doing the judging. Therefore, it's not efficient enough to evaluate the damage level of the materials objectively.

During a mass of field survey work on the ancient buildings' damage in the past, the author has always been confused with finding an efficient way to evaluate the damage level. Considering the various factors which caused damage of the old building, the present study aims at the most hazardous factor for safe conservation of the old buildings—the building dampness damage, and attempts to put forward a systematic field survey method for evaluating building dampness damage.

MAIN THEORY OF SURVEYMETHODOLOGY

Survey items based on the theory of dampness pathology

Building Pathology is a branch of science which explores how building diseases come up, develop, and transform. It aims to apply scientific methods to study the building pathology's origin, mechanism as well as its forms, characteristics, functions and developing process, and it also studies various methods to identify different building diseases, thereby to expound the fundamental principles and finally to provide the theoretical base to maintain buildings in a regular environment by radical cure or primary avoidance[2]. According to the basic principles of building pathology, building diseases can be classified into damage, crack, corrosion, freezing injury, seepage, ageing, and collapse etc from the aspects of disease properties[3.4].

Based on the mechanism of building diseases, in this study, the survey items of building diseases are divided into the following two categories. The first category includes 8 items, i.e., moisture infiltration caused by physical and chemical actions, weathering crack, surface fragileness, spalling fracture, deformation displacement, dump collapse and discoloration of the materials and others. The second category contains 4 items, scilicet timber corrosion, erosion by termite, fungi fielded, and plant parasitized by plants. Consequently a basic framework for survey items of building dampness pathology is put forward. (TABLE 1)

TABLE 1 : The basic framework for survey items of building dampness pathology

Mechanisms of Action	Pathological Features	Pathological Feature Illustration
Physical and Chemical Actions	Moisture Infiltration	Materials turn damp when immersed in water so that the water spots and stains come out on the surface
	Weathering Crack	Cracks, horniness, bulging of paint, expanding of under course turn up on the surface of materials
	Surface Fragileness	Alkalization appears on the surface of materials.
	Spalling Fracture	Speck drops or wags from under course, structural materials brakes.
	Deformation Displacement	Roof truss shifts, structural node slacks.
	Dump Collapse	Foundationdescending appears, even leads roof truss to tumble.
	Discoloration of the Materials	Paint of covering turns up chemicalmetamorphism, or dissolves and fades, adhered by dust and oiliness.
	Other Damages	Structuraltruss missing and any other damage.
Biological Actions	Timber Corrosion	Serious dampness parts of timber appear perishing, other parts of that turns up brown putrescence and white putrescence.
	Erosion by Termite	Insects such as termite, lyctus beetle and scoliid are able to erodetimber.
	Fungi Fielded	Parasitized by mucedine and mushroom.
	Parasitized by Plants	Parasitized by primary plants such as moss, lichen and fern.

TABLE 2 : Survey methods to building pathology problems

Survey Items		Survey Techniques	Methods Illustrations
Macro Survey	Primary Field Survey	Observation	Observational research and record of gap, damage,moisture infiltration and biological effect on material surface through eyes
		Touching and Smelling	Observational research on the symptoms of material erosion and biological effect by touching and smelling
		Knocking and Hearing	Using the resonancetheory on judging the densitydifference of material aperture, so as to judge the situations of materials rupture, bulging and aperture.
	Advanced Field Survey	Elastic Sense of Acupuncture	Using the reboundwave of metalneedlestabing to judge the solidness and erosion situations of materials.
		Instrumental Measurement	Measurecharacteristics of materials such as scale, damage situation and lean of truss.
Micro Study	Laboratory Diagnosis and Analysis	Analytical Test	Observation of material microcosmicstructure—SEM and chemicalanalysis of materialcomponent—EDS, XRD, XRF,FTIR
		Experimental Study	In laboratoryenvironment, design variouscondition and limitation to set systemicexperimental study on diversity of material variance.

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Common survey methods of building dampness pathology problems

The common survey methods of building pathology problems can be classified into two phases, the first one is a preliminary field survey, and the second one is laboratory diagnosis and analysis. The field survey can be divided into two parts according to the diagnostic levels. The first level includes observing, touching and smelling, knocking and hearing. The second level includes elasticsense ofacupuncture and instrumental measurement. The laboratory diagnosis and analysis can be divided into analytical test and experimental study. (TABLE 2)

TABLE 3 : Survey items appropriate for different building pathological characteristics

Pathological Features		Primary Field Survey			Advanced Field Survey		Laboratory Diagnosis and Analysis
		Observation	Touching and Smelling	Knocking and Hearing	Elastic Sense of Acupuncture	Machine Measurement	Analytical Test
Physical Actions	Stress Fracture	◎		◎	◎	◎	
	Moisture and Fragileness	◎	◎			◎	◎
Chemical Actions	Discoloration	◎				◎	◎
	Erosion of Inorganic Materials	◎				◎	◎
	Erosion of Organic Materials	◎				◎	◎
Biological Actions	Holes Eroded by Insects	◎		◎	◎	◎	
	Creature on the Surface	◎	◎				◎

EVALUATION OF DEGRADATION LEVEL OF THE MATERIALS BY DAMPNESS

The qualitative evaluation criteria for dampness disease level

The survey methods can be divided into qualitative and quantitative aspects. As for qualitative aspect, on-the-spot field survey method will be used, such as watching, touching, listening and so onto evaluate the dampness or crackness level of materials which would be helpful for researching record and the following analysis. (TABLE 4)[5]

The quantitative evaluation criteria for dampness diseases level

The main item of the quantitative aspect on the dampness of building material is the materials' moisture content (M.C.) survey. The apparatus which is being used is testo 606-1 material's moisture contents meter (electric resistance sensor, measuring conductivity). It has many advantages,i.e. light in weight (90g), high in precision (±2%), and fast in measurement speed (0.5sec), easily portable and has high resolution ratio (0.1%). Meanwhile, it has seven different measuring ranges that can be used in the measurement of materials with different moisture content like wood, concrete, mortar or

TABLE 4 : Degradation levels of building pathology

Level	Characteristic	Pathology Features
A	Extreme Serious	Layer of stucco materials on the surface is waged and dropped. Structural trusses are exposed in the open air or eroded.
B	Affect Greatly	Cracks, horniness, bulging, metamorphosis turn up on the surface of materials seriously, and the damaged materials can not restitute.
C	Some Indication	Liquid percolation and gasification expansion appear on the surface paint of under course and the interior of paint materials. What was more, it makes the materials bulgingmetamorphosis, besprinkled by gaps, or even erosion on paint.
D	Small Extent	Liquid percolation on the surface or interior of the materials, surface layer is wet and some is parasitized by mucedine or moss.

bricks. The appropriate temperature on the spot is between -10 and +50°C, which is just quite suitable for the field survey[6].

The present study mainly focus on the dampness level of the timber material. Since different characteristics on the surface would show up after the timber gets damp[7,8], therefore, in this study, the quantized evaluation criteria for dampness disease level is set according to the changing features of the materials and the limiting line between dryness and dampness is referred by the wood science[9,10]. It will be divided into 5 levels: A. arid, B. regular, C. damp, D. serious wet, E. soft rot. The moisture contents for the critical values are showed in the table below.(TABLE 5)

TABLE 5 : Grades of timber moisture level

Level	Situation	Critical Range of MoisturePercentage
A	Arid	0.00~7.00 %
B	Regular	7.01~14.00 %
C	Damp	14.01~20 %
D	SeriousWet	20.01~35 %
E	Soft Rot	35.01 % and more

CASE STUDY - PATHOLOGY ANALYSIS

This case of Taoist Classics Library lies in the ancient architecture complex of Jingding, WudangMountains in Hubei province. (North latitude 32°24', East longitude 111°00') (Figure 1) From the preliminary observation of the survey environment, we know that the moisture conditions are quite serious on the east side of the eaves aisle, which is where our survey project starts. The survey splits into two parts: the timber corrosion condition, and the timber moisture condition.

It can be clearly seen from the survey spot that the bottom of the timber pillar near plinth is seriously rotted. It is caused by the corrosion and was once repaired with putty. During this survey, we use moisture content meter to test it. It can be known from the results (Figure 2) that the M.C. in the eaves pillar is over 20%. Such an obvious difference, determined from the site situation, might be related to the ground water pressure in the basement material, that is to say, the soil under the basement of the eaves pillars is rather damp

Figure 1 : Case study- the taoist classics library in wudangmountains.

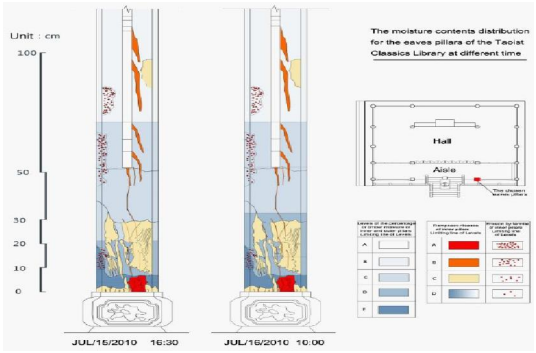

Figure2 : Building pathological surveys for dampness disease in eaves pillars

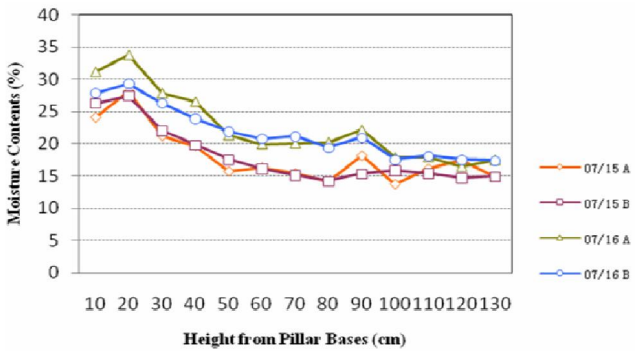

Figure 3 : The moisture contentsdistribution for the eaves pillars

with high moisture content leading to the high capillary pressure in it. (Figure 3)

Disease characteristics, such as soft rot, cracking, and erosion are all related to the M.C. in the timber. According to the survey result we know that the environment in which the M.C. is over 20% (level D, E) is faced with the disease threats of soft rot, and serious cracking. While as to the environment where M.C. is below 20% (level B, C) is mainly faced with the threats of cracking, erosion etc. What's interesting during the survey is that because of the direct sunlight, the sunny side of eaves pillar cracks badly due to the temperature shock inside the timber, but the shady side would always stay damp so that worm holes spread all over.

DISCUSSION OF SURVEY METHODS: PATHOLOGICAL DIAGNOSIS OF TIMBER MATERIAL BY MOISTURE CONTENT SURVEY

Study on the erosion holes inside timber material using the difference of the moisture content

It is known from the survey that material type is not the only factor that influences moisture content, structure pattern of the material and its void content also work, such as biological erosion holes, decayed pulverization and so on. Moreover, the ultimate differences are quite obvious. If the inner part of timber is seriously eroded, and the fiber structure turns into a cavity with poormoisturizing of pore water, then the M.C. in the timber would drop promptly. We can make a preliminary judgment about the position or range of the large holes formed through the sudden change in M.C.

After several case studies and tests, similar rules are found. Here a case of Zhans' ancestral hall of Shitouban village, Muzidian town, Macheng city,Hubei, China (North latitude 31°11', East longitude 115°22') is taken as an example. (Figure 4, 5)

Figure 4 : Case study-zhan's ancestral hall of shitouban village

Figure 5 : The timberbeam on the stage

This survey was carried out with testo 606-1. The measure point setby the grid with divided equally in horizontal direction every 25cm, and in vertical direction every 6cm. The result (Figure 6) shows that the M.C. in the regular part of the beam distribute among 10~16%. Figures in the middle part (h,i, j point) are rather high, and the points at the bottom side of the beam turn out to be more damp than the upper side points. The difference of M.C. is all within 2%. However, the M.C. of the beam didn't spread symmetrically. From this result, we find that for one part of the beam, the M.C. promptly drop, and for the point 1m away from the support joint, the figure is quite low. It has the lowest value of 2% with a quite high difference which is 8% at the most.

How does it happen? The method of "knocking

and listening" was put into practice. We findthat the density of this part is totally different from that of the other regular parts, which means that it's quite fluffy inside, and has large, wide-spread void holes. Has it already seriously eroded or rotted? To prove this hypothesis, we took the appropriate part and cut it up for a careful observation. The results showed that the inner part of the wood has been badly eroded and has become pulverized.

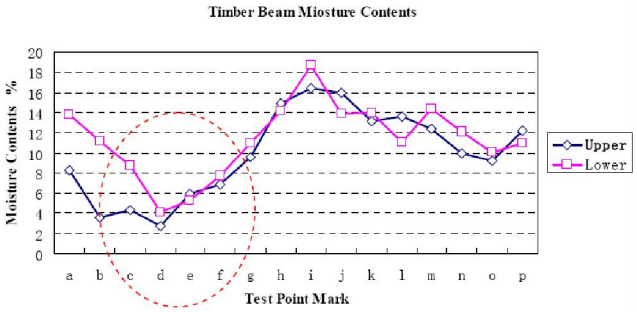

Figure 6 : Moisture contents of timber beamof the stage

In conclusion, when the inner part of the timber material gets seriously eroded and pulverized with many erosion holes on the surface, the moisturizing capacity of the inner fiber formation of timber material will decrease linearly, which leads to the dryness inside the timber material. Therefore, by using of the features that the M.C. for some parts of the timber material will drop promptly, together with the simple technique of "knocking and listening", we can easily judge the erosion holes and the pulverization situation on the fields simply, economically and efficiently.

Study on the limiting ranges of timber dampness and rotten through the differences of m. c.

Anotherphenomenon found from the survey is that, when the environment where the timber pillar stay is too damp, the M.C. differences inside the timber material can be told from the surface features, so the range values can be determined in the very primary step. Once the timber pillars get damp, different moisture contents show different features on the surface. The dampness degree can be judged through touching and observing. Generally, the damp and dry grains on the surface have the following features: A. light-brown wood grain when it's normal; B. dark-brown wood grain when it's damp; C. dark-brown wood grain with green moss when it's too damp. It and whether the timber structure is hard or soft, strong or loose also can be judged by knocking, which will tell you the dampness degree. It has been surveyed that the dark-brown timber material with moss in the over damp environment feels more like soft corrosion, apparently different from the rigidity in other parts. (Figure 7)

Figure 7 : Situations of the dampnesspillar

This is a case of YangzhouVillage in Yangxin County, Hubei, China(North latitude 29°39', East longitude 115°10'),which helps us to know the moisture situation inside the material through the qualitative judgment based on surface features. The timber pillar in Li's residence will help to explain such a situation. (Figure 8)

Figure 8 : Case study – the timber pillar in li's residence

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The survey included 4 time intervals. The place where the timber pillar stood suffered continuous pouring rain. During the 4 time intervals, it cleared up after the rain (temperature out there went higher gradually, and the relative humidity went down). The result showed that the moisture contents in this timber pillar ranged from15% to 40%. (Figure 9)

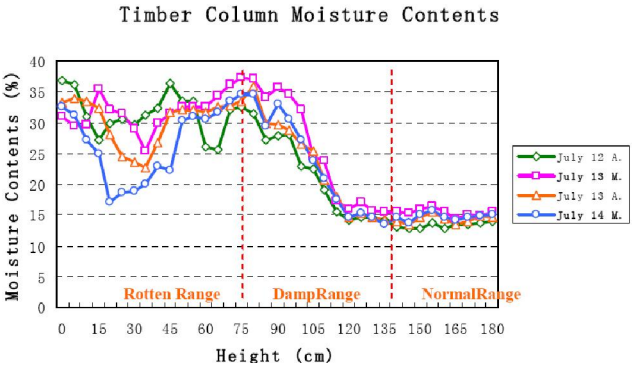

Figure 9 : Moisture contents differences of timber damp and rot

It can be told from the measuring data, that the moisture characteristics for timber pillar can be split into 3 sections: A. steady state section, this part is over 120cm high from the bottom part of the column, and the moisture content is about 15% with small data variations; B. regular changes section, this part is between 55 and 120cm high, and the moisture content ranges from 15% to 40% with regular changes; C. disordered changes section, this part is between 0 and 55cm high, and the moisture content changes in disorder and with damp conditions all over.

During this survey, we found that the 3-section data variation of the dry and damp timber grains happened to show up too: A. steady state section, normal light-brown timber grain; B. regular changes section, damp dark-brown wood grain; C. disordered changes section, over damp dark-brown timber grain with moss.

Would it be possible for us to distinguish the timber's dryness section from that of dampness according to the characteristics in moisture content differences as well as material surface features? Normally, the M.C. lay between 8% and 15% and it might be 35% to 40% when the timber gets soft rotted[11]. Timber in steady state is in normal conditions with M.C. of about 15%, which means that the absorbed water inside the timber is what exists originally but not from the damp environment, and the surface looks dry. Thus, this section can be known as "normal section". The timber with regular changes can still be considered as "healthy". It stays good in structure since it hasn't been rotted softly so that it has strong potential to absorb and store moisture inside the fiber material. When the water is sucked in, it goes into the fiber pores and is hard to be influenced by the climate changes out there, so the survey results show us some regular rises and falls. The timber in damp conditions looks damp on the surface too, and it's called "damp section". The disordered data means that the M.C. inside the material was influenced by the dry or damp environment in the outside world. When the weather turned from rain to sunshine, the relative humidity in the air gradually fell as the temperature went higher, and the M.C. in timber columns went lower accordingly. But why this happens? From the structure of the timber material, we know that since the timber organization gets looser, the fiber organization breaks down, thus, the moisturizing capacity goes down, which makes the absorbed water inside fiber pores more likely to be influenced by the humidity in the air. So the damage of the timber fiber organization is caused by soft rot, which is defined as the "rotten section".

Therefore, this study gives a definition to the timber dampness and rotten decay section (TABLE 6), and demarcates between dampness line and rotten decay line as in: A. dampness line—between normal section and dampness section; B. rotten decay line—between dampness section and rotten decay section.

Thus, we know that this method to judge whether the structure of timber fiber material is "healthy" or not is to measure M.C. in one structure material at different

TABLE 6 : Different characteristics of timber material in different sections.

Sections	M.C. Characteristics	Height	Characteristics of the Surface	Sense of Touch	Percussion Echo
Normal	Steady changes around 15%	Over 120cm high from the bottom part of the column	Normal light-brown wood grain	Dry; Puckery	Material is hard with clear echoes
Dampness	Ranges from 15%~40% with regular changes	Between 55~120cm high from the bottom	Dark-brown wood grain	Damp; Smooth	Material is hard with nepheloid echoes
Rotten Decay	35%~40% with disordered changes	0~55cm high from the bottom	Dark-brown wood grain with moss	Wet; Soapy	Material is soft without echoes

time points and compare them, or, to directly observe the surface characteristics of it so as to judge if it's in normal condition or dampness, or even rotten decay, combining with the means of touching, knocking etc. In this way, we can do some simple, economical and effective primary on-the-spot tests during the field survey.

CONCLUSION

Dampness is the fundamental factor in affecting protection of heritage materials, especially for timber. In heritage renovation, craft technology study which focused on practical conservation is valued greatly previously. While, study concerning conservation of primary characteristics of the materials and exploring study of the pathological mechanism caused by the external environment are valued these years.

There are various factors which would have harmful effects on the heritage materials in the preservation environment. Thus, the disease characteristics formed by these factors are multiplicated. As a result, effective use of data collection measure in spot survey and provision of reliable information can be taken as references in future conservation practice.

The present study is preliminary in exploring the fieldwork technology of moisture phenomenon. While, exploration of the exactmechanism of material pathology needs systematicresearch in laboratory. Such a project requires the attention of the whole professional environment and such a day will come in the recent future.

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