Need for Nondestructive Evaluation (NDE) in the Detection of Decay in Structures[1]

W. Wayne Wilcox[2]

Abstract: Examples of the need for nondestructive and remote sensing technologies for evaluating early stages of decay are presented. The need is critical to develop methods of analyzing internal decay, at the center of large wood members, and decay behind concealing coverings. Current technologies are reviewed and their inadequacies discussed. Acoustic emission and acousto-ultrasonics appear to hold the greatest promise among existing technologies.

Sometimes, nondestructive evaluation (NDE) is not needed to determine that a potentially serious decay problem exists in a building. If the plywood siding, a hand railing, or a major glulam beam sprouts mushrooms (fig. 1), for example, you can be pretty sure you have a decay problem on your hands. Unfortunately, those are rare occurrences. White mycelium growing on the surface of wooden structural members in moist areas (fig. 2) is also a pretty good clue that you should be concerned about the structural integrity of the member involved, but that, too, occurs relatively infrequently in structures. Once the structure is opened and advanced decay is revealed, little additional information is necessary to assess the structural impact of the decay in many cases. But, in the majority of cases of wooden structures with water problems, visual indicators are not present and some form of internal assessment must be incorporated.

Figure 1--Mushrooms on exterior glulam (courtesy of W.A. Dost).

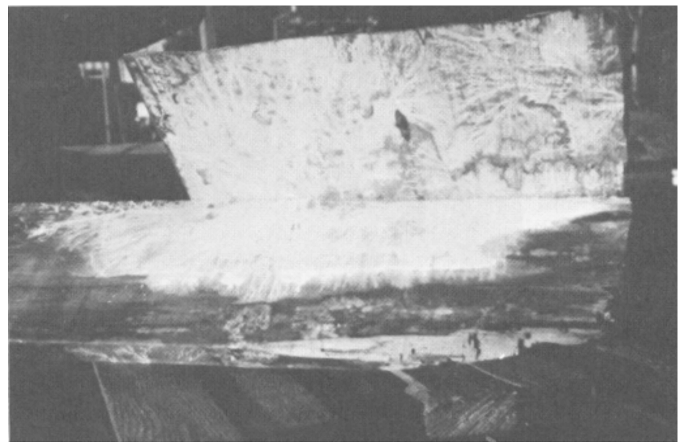

Figure 2--Mycelial mat on joist and underside of plywood subfloor.

Two broad categories of internal decay are encountered in buildings. One is where wood is exposed to the weather and is sufficiently open that the surfaces of the wood members remain dry enough that any decay occurs inside the member without telegraphing to the surface (i.e., internal decay in exposed members). The second circumstance is where wooden structural components are contained behind surface finishes which effectively conceal any evidence of the decay process.

Here are some examples of both such circumstances.

An A-frame structure supported on glulam beams which extend beyond the perimeter walls and roof-line allowed the glulams to be subjected to internal decay (fig. 3). No external evidence of decay was apparent, but probing revealed sufficient softness to warrant concern for the structural integrity of the members. A combination of increment boring and ultrasonic pulse timing provided sufficient evidence of advanced decay to convince the engineer that reinforcement was required (fig. 4).

Elsewhere, the entire Indian Valley College campus was temporarily condemned while exposed glulam beams were investigated and a structural solution was

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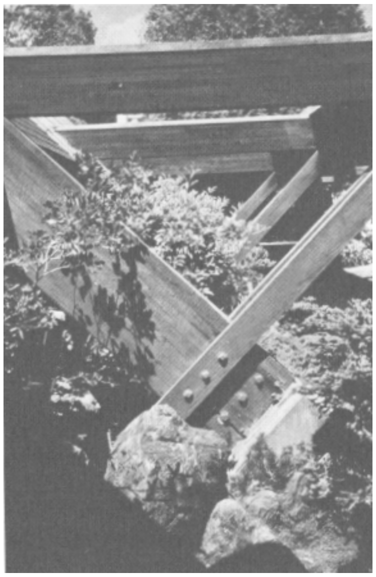

Figure 3--Glulam and connections exposed to the weather.

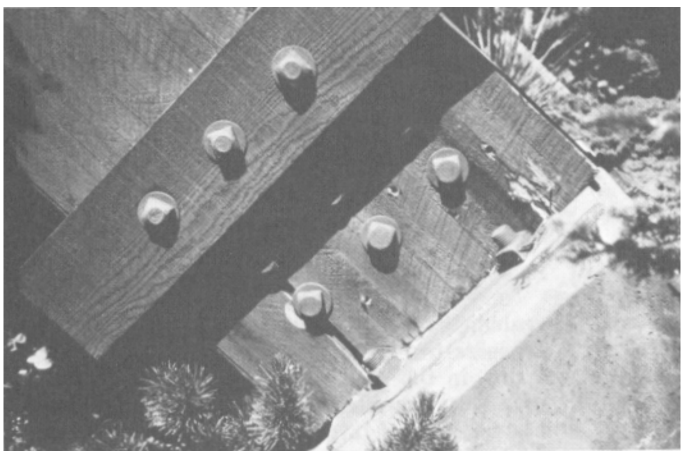

Figure 4--Internal decay was found by boring and ultrasonic pulse timing.

developed. This design proved particularly difficult, since glulams played such an important role in all structural aspects of the building, from lateral and vertical support to floor and roof support, blocking and decorative trim. However, even glulams used as nonstructural elements for their esthetic appeal can constitute life hazard if they fail. Decay initiated in exposed parts of large members may extend past the perimeter wall, through load-bearing areas and into the interior of the structure. Although evaluation of internal decay in exposed members currently presents significant challenges, at least it is possible; evaluation of decay which extends into the structure is often impossible without major demolition. These are two different challenges for NDE.

For some time, there was a significant tendency on the part of designers to expose glulams to the weather on the outside of the building for esthetic reasons. We now know that this is not a good idea. Once the major check system develops in the top of a glulam in exterior exposure, it appears to be doomed. Even solid timbers exposed to the weather, with numerous contact points and bolt holes (fig. 5), present a significant hazard, because water is trapped long enough to be absorbed.

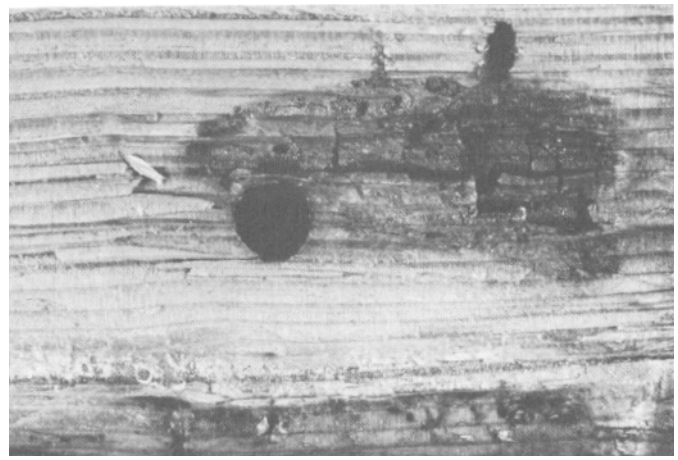

Figure 5--Solid timber with internal decay around a bolt hole.

In both of these cases (exposed glulams, and timbers with exposed joints and fastenings) it might be justifiable to just call for removal in any structure over six years old, and you would not be wrong too much of the time. However, because you would end up removing some perfectly sound wood if you operated that way, and also because the people paying for such treatment usually demand fairly firm evidence of a problem before being willing to expend the large sums of money involved, some sort of internal property evaluation is necessary. As far as destructive sampling goes, if it turns out to be decayed, it does not matter that you have put a rather large hole in it. However, if it turns out to be sound, then it would have been better to have had a non-destructive method of analyzing the interior of the member. Sometimes the life hazard involved in the failure of an individual wood structural member is so great that a means of continually monitoring its strength, as part of preventive maintenance, would be an extremely valuable tool. This is another role which NDE could play.

In all the previous examples, at least portions of the wood structural members were exposed to view. However, often, structural members are covered with a material which effectively conceals any evidence of the existence of a decay problem. Stucco probably is the most troublesome, and common, example of such covering. In one case, glulam beams and solid wood columns were encased in stucco and, in the corners, were affixed with planter boxes containing their own irrigation system. Unfortunately, this system irrigated both the soil and the supporting wood structure, causing decay (fig. 6) which was not at all evident behind the stucco (fig. 7). Although the prior example was inside a structure, stucco is most commonly used as an exterior finish. Both inside and out, stucco is just as concealing and, at the moment, requires actual demolition in order to assess the condition of wood beneath it. Remote, nondestructive assessment is truly needed where stucco covers structural wood.

An elastomeric compound, which mimics stucco, failed miserably when applied directly to plywood siding. Because it acted as a membrane, the cracks which developed let water in but the uncracked portions prevented it from getting back out. Therefore, it was both part of the decay problem and the concealment of the problem.

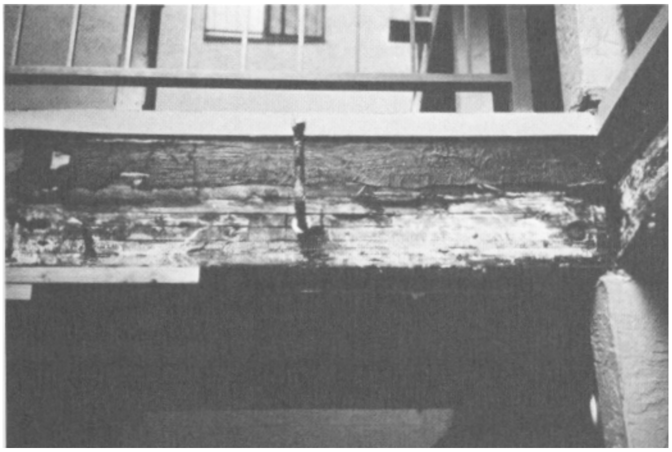

Figure 6--Decayed beam which was behind stucco as in Fig. 7.

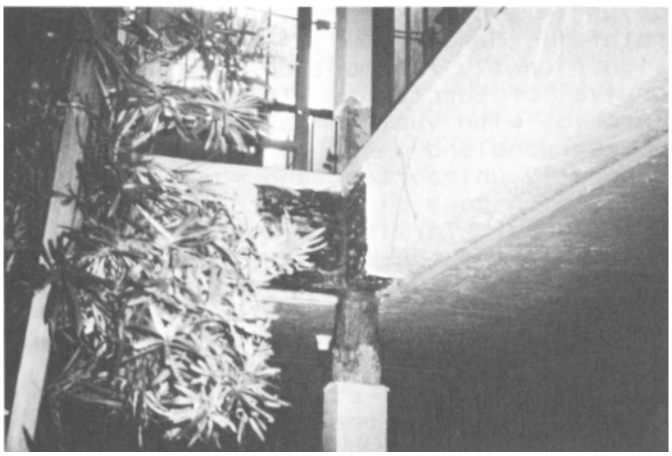

Figure 7--Stucco wall showing no external evidence of decay behind it.

At the time of this writing, the most reliable field test available for diagnosing decay is the "pick test." Unfortunately, it does not begin to become reliable until the equivalent of approximately 10-15 percent weight loss, at which point a significant amount of wood strength has already been lost. Also, it is effective only when decay is present on the surface, which is frequently not the case with major wood structural members in exposed service. An effective way of examining the inside of a large member is to use an increment borer. This instrument produces a core of actual wood from the interior of the member, which can be either visually examined or microscopically evaluated. Microscopical examination can effectively diagnose decay in its earliest stages, before significant loss in strength. However, it is an arduous, time-consuming and highly specialized technique which cannot be applied to a large number of wood members, and still leaves behind a hole.

Probably the most commonly used device for detecting decay in the field is the screwdriver, or some other type of penetrating probe. Probing allows evaluation of both the hardness of the wood (a strength property not particularly sensitive to early stages of decay), and its toughness (which is very sensitive to early stages of decay) through application of the "pick test." When a building is undergoing evaluation for the presence of decay in structural members the screwdriver is likely to be present. However, information gained from probing may be misleading.

Properly evaluated and maintained, wooden buildings are capable of providing long service. Around 250 years is about the best that we can show in this country. But elsewhere, over 800 years can be demonstrated.

The big problem is that most of the strength of wood is lost in such an early stage of decay that we have no current field-applicable technology capable of evaluating it with reliability. Professional judgment and experience may be our most effective current means of evaluating decay in structures. Actually, the intuitive expertise we've developed, out of necessity, may be an impediment to the development of electronic technology. A fairly recent survey by Barry Goodell and Oregon State University (Goodell and Graham, 1983) found that a majority of utility pole inspectors are confident that they can detect early stages of decay by hammer soundings!

Moisture meters are used in the field, and can indicate whether wood is in a moisture condition capable of supporting decay. Units with long insulated pins are capable of giving such information, even from the inside of a member. This technique, however, does not allow evaluation of strength loss. A sonic device has been in use, by utilities, on poles for many years and appears to be effective in locating advanced decay and voids. However, there is no information to suggest that it can detect early stages of decay. Experiments have shown that ultrasonic pulse transit time measurement is capable of detecting early stages of decay in some circumstances, but not others (Wilcox, 1988). Acoustic emission under compression appears to be extremely sensitive to early stages of decay, but is not nondestructive (Beall and Wilcox, 1987). Acousto-ultrasonics appears to be able to detect early stages of decay under nondestructive application, but has not yet been adequately researched to know for sure. (The primary difference between acoustic emission and acousto-ultrasonics is that acoustic emission testing involves analysis of sound being generated within a material being stressed, whereas acousto-ultrasonics involves analysis of sound which has traveled through the material but is induced by a source external to the material being tested.) Resonant vibration and electrical resistance methods may bear promise for nondestructive evaluation of wood structural members, but are just beginning to be researched for this application.

There is a need for more sensitive tools for inspecting wood structural members for damage zones and wood decay. Significant efforts are in progress to apply emerging technologies to the evaluation and inspection of wood members. These tools are being developed considering the need to correlate NDE measurements with member strength and stiffness. Whether such technology can be developed for nondestructive application in structures remains to be seen.

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Termites and Forest Management in Australia[1]

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Abstract: Termites have long been regarded as major pests of Australian forests. Drawing together research on termite ecology and mammal conservation, this paper argues that this perception is wrong; termites are a vital component of native forests.

Australian forests are dominated by eucalypts. More so than on any comparable landmass, Australian forests are characterized by members of this one genus comprising more than 450 species[3]. Eucalypts first appeared 35 million years ago, and are believed to have evolved on the margins of the then extensive rainforests. With climatic change and the retreat of rainforests in the late Tertiary, distinct seasons arose and the great radiation of the eucalypts began as adaptation to varying water supply became favored (White 1986).

The second major genus of Australian forest trees is Acacia, the wattles. Although Australia has more than 600 species of Acacia, they rarely dominate forests, and usually form an understory below a eucalypt canopy. Wattles are relatively resistant to termites, and standing wattles are mostly degraded by beetles. The third major genus, Callitris, is the only mainland gymnosperm to form extensive forest and occurs widely in semi-arid regions of eastern Australia. Callitris is particularly resistant to degradation by termites[4].

Australia has very little forest. In a land mass of 760 million hectares, only 42.5 million hectares, less than six percent, are forested. These forests occur in a coastal belt, limited by rainfall (Senate 1977), and have been significantly fragmented since the arrival of Europeans. Inland Australia is arid, with vast areas of extremely sparse woodland where herbivory is generally unimportant and much of plant production goes directly to the detrivores. Termites are thus very important and these inland regions may be thought of as lightly wooded deserts with a fauna dominated by termites, ants and lizards. Recent studies (Tongway and others 1989) point to termites as promoters of small-scale fertile patches which are refuges for many desert plant species.

LOSS OF TIMBER TO TERMITES--HISTORIC PERSPECTIVES

The earliest records of termite damage to timber in Australia date from the late nineteenth century and report the impact of indigenous termites on introduced horticultural tree crops and vines (French 1893). At this time most of the timber produced by forest clearing was simply burnt, and it was not until the native forests were commercially harvested on a large scale that the activities of termites received attention.

Thirty years ago--even five years ago-- I would have reported that termites are major pests in Australian forests, that they consume large quantities of merchantable timber and that the intensity of their attack is often much greater than in other bioregions (Carne

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[3]Although Eucalyptus is still a single genus, revision of the genus was first suggested by Carr and Carr (1959). Pryor and Johnson (1971) recognized four subgenera which in a later (1981) paper they regarded as being equivalent to genera, but did not promote at that time. It is probably only a matter of time before the group is revised into at least four genera (Florence 1981).

[4]For tabulations of the durability of Australian timbers, see Johnson and others (1986).

and Taylor 1978, Greaves and others 1967, Greaves 1962b, Harris 1966, Perry and others 1985, Ratcliffe and others 1952).

The first researchers calculated the “cost” of termites in terms of the volume of timber lost" by surveying the extent of degraded timber that contained evidence of termite activity. Studies showed that in both highland and lowland forests, termites "reduced" timber yield by 25 percent or more (Greaves and others 1965, 1967). This indicated loss in potential profitability lead to novel control proposals, including the treating of individual trees with arsenic trioxide or organochlorines applied by injection, the removal of all mature trees that might potentially harbour termites and the replacement of susceptible native forest with plantations of Pinus spp. (Greaves 1959, Greaves and others 1967). However, with the exception of conversion to pines, none of these termite control measures have ever been economically feasible.

In the main, only five termite species are responsible for almost all of the attack in commercial Australian forests. The primitive Giant Northern Termite (Mastotermes darwiniensis Froggatt) (Mastotermitidae) is a major impediment to tropical forestry, the dampwood termite (Porotermes adamsoni [Froggatt]) (Porotermitidae) occurs in cool or mountainous forests along the eastern seaboard, but by far the most important are of the genus Coptotermes Wasmann (Rhinotermitidae): C. acinaciformis Froggatt (C.a. raffrayi in Western Australia), C. frenchi Hill and C. lacteus (Froggatt).

Species of Coptotermes are very adaptable; they may nest in the ground, in mounds of their own construction, or in trees. Their distribution in Australia is almost as wide as the eucalypts they eat: desert, woodland, cool temperate forest and rainforest (Calaby and Gay 1959).

ATTACK ON TREES

Termites prefer to consume decayed wood (Wood 1978, French and others 1981, 1987) and there is evidence that they are healthier if they do (Hendee 1935, Lenz and others 1980). Attack on trees is more likely to occur when the tree is wounded (Greaves and others 1965). Colony formation by founding-pairs is through scar tissue, typically reported to be fire scars at the base of trees (Greaves and others 1965, Perry and others 1985), but entry through less easily observed routes such as branch stubs, damaged roots and the exit holes of beetles and moths is also probable. Attack is also initiated when termites extend galleries in the soil and enter other trees, typically from galleries running on the underside of roots and entering the heartwood at the root crown, a habit common in Coptotermes. This method of attack may occur over distances of 50 meters with a single colony feeding on more than 15 trees (Greaves 1962a) and is eased by the high incidence of natural root grafting among eucalypts (Ashton 1975).

Coptotermes build a central nest, at the base of the tree, with the nursery being below ground level in cool climates and elevated in warmer areas. The termites consume the heartwood, as its natural anti-feedant chemicals degrade through decay organisms and natural ageing. Porotermes consume the timber in a similar manner, but do not maintain a central nest, rather, they work through the tree as a travelling population. Thus the main "pest" species are consuming dead and decayed heartwood and decayed areas of timber which are of negligible commercial value. Rather than being primary agents of timber degradation, their presence is secondary: an effect rather than a cause. Timber is not a limiting resource for the termites, but appropriately degraded timber is; termites select their food for the presence of appropriate decay.

Shigo's model of compartmentalization of decay in trees (CODIT) (Shigo 1984) is widely ignored by Australians (see, for example, Perry and others 1985), but the patterns of termite activity in eucalypt timber closely follow Shigo's predicted areas of response. His model is particularly useful in understanding the co-evolutionary balance between termites and trees: although termites feed within the tree, the tree is able to limit their activity and protect its structural integrity, by compartmentalizing scar tissue. It does a tree no harm to be hollowed and may even provide some structural advantage (Dickinson and Tanner 1978, Janzen 1976). The longevity of termite infested eucalypts show that this balance between growth and consumption may be held for more than two centuries, with the process of hollowing extending into all the main branches.

Early growth of eucalypts concentrates on the attainment of height.

Crown growth dominates mid-life, with maturity occurring when the crown reaches the limits of dimensional stability. The term “overmature” is used to describe trees where the growth of the crown is balanced by more or less continual branch shedding. Most young trees do not suffer termite infestation until about 70 cm dbhob[5] although the risk is greater where injuries have occurred (Carne and Taylor 1978, Elliott and Bashford 1984, Mackowski 1984).

Fire is considered to be the major cause of such injury (Elliott and Bashford 1984, Perry and others 1985), particularly when prescribed burning is involved. Even where eucalypts are planted as exotics, termite attack is secondary to some other stress-causing factor (Chatterjee and Singh 1967). Any significant breach of the tree's defences will result in the formation attractive scar tissue. Thus today, a tree's chances of early termite infestation are increased by roading and logging machinery, which cause mechanical damage to the cambium at the base of trees and also, by logging and silvicultural thinning due to collisions with falling trees.

However, my observations in the Boola Boola State Forest in eastern Victoria (Ewart 1988) suggest that regrowth is being rotated while it is too small to support large colonies of the major pest species. These termites require large timber for nesting, and attack on small regrowth trees is most commonly initiated from colonies located in remnant old-growth trees or stumps. Thus while management may make more palatable timber available to termites, the populations of termites will diminish drastically, unless sufficient colony-sites remain.

SPECIES DEPENDENT ON TERMITE-CREATED HOLLOWS

The excavations of termites alter the structure of trees and provide spaces which have become a necessary part of the habitat of many vertebrate species. These beneficial activities are increasingly recognized by wildlife researchers (Ambrose 1982, Mackowski 1984, Saunders 1979) but remain largely ignored by termite biologists (e.g. McMahan 1986). Termites do not create these hollows directly; their excavations, apart from the minimum space needed for access, are quickly filled with mud and feces ("mudgut”). Mudgut pipes may extend the full height of the tree and into each of the major limbs. Eventually the mudgut column compacts under its own weight or erodes as water enters through openings created by shed branches. This creates cavities which other animals readily utilize.

A wide range of bats, birds and arboreal marsupials are entirely dependent on hollows of particular volume, depth and opening diameter for nest sites. Australian vertebrates, unlike some of their northern hemisphere counterparts, do not excavate their own tree hollows but are limited in their efforts to minor maintenance, relying instead on the actions of termites.

Fallen, hollowed limbs and trunks of overmature trees provide habitat for ground-dwelling reptiles and mammals. A particular example of this is the specialist termite eater, the Numbat (*Myrmecobius fasciatus* Waterhouse) (Marsupialia: Myrmecobiidae). Numbats feed exclusively at secondary aggregations of termites on the forest floor and require numerous hollow logs for shelter. They were once widespread across southern Australia, but their range has now been reduced to a small area of southwestern Australia due to the loss of habitat (Christensen and others 1984, Friend 1982). Wildfire and logging reduce the supply of suitably hollowed fallen wood and without shelter, numbats quickly fall prey to the introduced European foxes.

FUTURE MANAGEMENT CONSIDERATIONS

Typically, a eucalypt does not develop hollows until between 90 to 120 years old, well after the age at which termites begin to feed, but also well beyond the present 40 to 80 year age at rotation. Management prescriptions call for the retention of a few overmature "habitat" trees in each logging coupe. However, although eucalypts may persist for two to three centuries after developing hollows, they will in time die and eventually fall. Thus the prescriptions are inadequate because they make no provision for recruitment to replace these habitat trees as they are lost.

The impending threat to wildlife populations is potentially serious. Populations will decline rapidly as nest sites become limiting. Even if corrective action is taken immediately, many forests will soon face a gap of a

[5]Diameter Breast Height Over Bark.

century or more before another generation of suitably hollowed trees can develop (Mackowski 1984).

This problem is compounded by the negative effects of logging on the retained habitat trees: few will be able to live to their full potential as the coupes in which they stand will be logged between three and seven times during this period. The cost of providing artificial hollows during this period will be enormous. Thus in areas where multiple use management includes the maintenance of wildlife, there is a need to retain not just habitat trees but also cohorts of replacement trees and populations of termites to transform them. Managers of native eucalypt forest need to change their perception of termites: termites are not pests, but have a vital role in forest ecology and must be seen as an intrinsic part of the system.

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