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The Effects of Roots Action of Tropical Green Roofs—Replication of German FLL in Singapore

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***Abstract*—**Green Roofs offers numerous advantages, including lowering ambient temperature, which is of increasing interest due to global warming concerns. However, there are technical problems pertaining to waterproofing to be resolved. Currently, the only recognized green roof waterproofing test is the German standard FLL. This paper examines the potential of replicating the test in tropical climate and reducing the test duration by using pre-grown plants. A three year old sample and a new setup were used for this experimental study. The new setup was prepared with close reference to the FLL standards and was compared against the three year old sample. Results showed that the waterproofing membrane was damaged by plant roots in both setups. Joints integrity was also challenged.

***Keywords*—**Building plants, green roof, sustainability, waterproofing membrane

I. Introduction

GREEN roof was already used by the Ziggurats since the fourth millennium for reducing solar radiation of roof and protection from extreme colds [1], [2]. In the modern era, Germans have also used green roof over the past four decades [1]. They have one of the most advanced green roof technologies in the present day.

Other countries are trying to catch up on what they have missed; United States has setup the U.S. Green Building Council to promote the advantages Green Roofs. Tokyo, Japan, is also the first Asian city to legislate the minimum green coverage for built-up roof for new constructions [1], [3], [4], following precedents from Europe like Stuttgart's legislation for new flat roof industrial buildings. Even the city of Toronto, Canada has listed green roofs as one of the means of promoting a Green Economy, an economy which a healthy environment complements a vital economy.

Singapore also tries to embrace green roof, clearly illustrated by the pilot project of Housing and Development Board and National Parks Board in Punggol.

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These large scale adoptions are due to the numerous advantages green roofs offer, including [2], [5], [6] [7]:

- improves thermal performance of the roof;
- reduce "urban heat island effect";
- improves rainwater management by reducing runoff quantity;
- prolong roof life;
- improves air quality;
- reduction of pollutants;
- reduce effects of global warming;
- cost savings; and
- visually attractive.

However, due to the nature of the construction industry and the scale of building projects, it is almost impossible for a building to be defect free, including green roofs. Defect on green roof waterproofing membranes are reported in [10], as shown in fig. 1.

Fig. 1 Roots leaving impression on waterproofing membrane, adapted [10]

Furthermore there were many defective green roofs in the United States in the 1970s [6], [9]. Although waterproofing materials are of higher quality today, due to better materials and manufacturing processes, defective waterproofing due to poor workmanship is still present. In addition, the suitability of a material cannot be verified, easily, especially for tropical climate. Moreover developers and architects feel that green roofs will damage waterproofing [8]. Therefore, a local study was performed to address root action on green roof waterproofing membrane.

Moreover, the damage ability of roots cannot be underestimated. Tree roots penetrated concrete dam, illustrating the extent of damage which roots can cause [11]. Although tree roots are much larger than roots of plants used on green roofs, the possibility of root damage to green roof waterproofing cannot be ignored.

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A. Green Roof Waterproofing Testing Methods

Currently, there is only one testing method for green roof waterproofing, the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) test, or commonly known as the German FLL test. Other tests, like the Swiss SIA test, and American ASTM test, do not specifically test for green roof waterproofing. These tests are only typical waterproofing tests but they are used by waterproofing manufacturers to qualify that their waterproofing satisfies these tests and are suitable for use on green roofs. This is not desirable as a green roof condition is different from a conventional roof. The temperature experienced will be lower due to shading from the planting layer. However, the amount of time which the waterproofing will be in contact with water is much longer. Hence, the ASTM and SIA tests are not recommended to be used for testing for green roof waterproofing.

B. FLL Standard Test

The FLL guideline sufficiently covers the waterproofing aspect and other green roof elements. This testing method is conducted over 4 years. It also includes the strength of the membrane and the jointing of the membrane.

However, this testing method has several obstacles in terms of adaptation in the tropics:

- different climatic conditions;
- different plants species; and
- duration of test.

The objectives of this study are therefore:

1. to examine the effects of root growth on waterproofing membrane on tropical Rooftop Garden;
2. to act as a feasibility study for accelerating Rooftop Garden waterproofing membrane tests.

II. Methodology

Two samples were used for this experimental study. Sample 1 is acquired from a previous Rooftop Garden study whereas Sample 2 is a new setup. Sample 1 was a three years old setup for a study examining the thermal protection of vegetation on green roofs. It is selected because the duration of this setup is comparable to that of FLL (4 years). It serves mainly as a basis of comparison against sample 2, to determine the performance of sample 2 design, evaluated based on the study objectives.

Sample 2 is an experimental box with a simple waterproofing layer followed by soil and plant layers. The waterproofing of sample 2 is designed based on common laying methods of sheet waterproofing.

At the end of the experimental period, soil was being removed with a water jet for root study observation. The integrity of the waterproofing layer was also studied at close distances.

A. Setup of Sample 1

The main components of setup 1 are:

1. raised platform;
2. concrete slab of 100mm thick;
3. soil of about 200mm thick;
4. waterproofing membrane;
5. perspex enclosure; and
6. plants.

The horizontal waterproofing is a sheet applied membrane, without any form of adhesion to the concrete slab. There were also no joints. Liquid applied waterproofing is used to seal the joints between the horizontal waterproofing membrane and the vertical perspex enclosure. Information on materials used for waterproofing could not be found.

B. Setup of Sample 2

Sample 2 measures 500 × 500mm. It consists of a metal frame, wire mesh base, perspex enclosure and plastic sheets of about 2mm thick acting as waterproofing membrane.

A wire mesh base was used instead of a perspex sheet because it allows for immediate detection of root penetration through the water proofing membrane. If perspex had been used as the base, though visual observation is possible, there might still be some presumption as the waterproofing membrane is only 2mm thick. Detecting penetration across the perspex would be difficult.

Perspex is used for the enclosure of the sample as it allows visual inspection of any root growth at the side of the sample box. A drainage hole is provided, 15mm from the base of the box, on one side of the sample box, so as to prevent over-collection of water.

Lying of the waterproofing membrane adopted the FLL guidelines. Waterproofing membrane consists of 3 separate sheets, to simulate jointing practices. Fig. 2 shows the layout of the membranes at the base of the setup.

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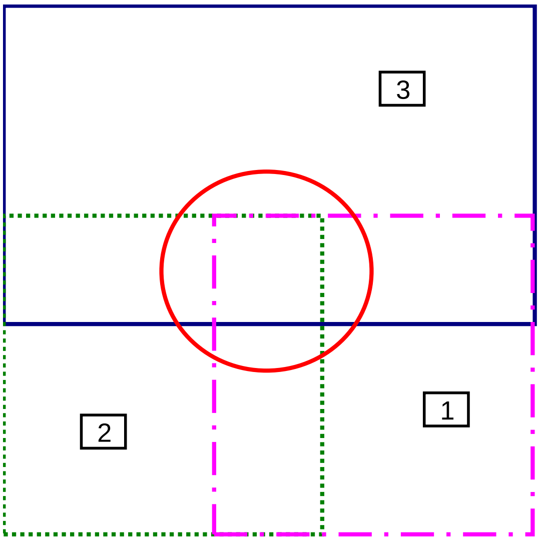

Fig. 2 Layout of the membrane sheets (no. in box indicates order of lying)

This is to simulate the commonly practiced lapping of pre-formed waterproofing membrane during lying.

Pre-grown plants are used as a form of accelerating the experiment. In addition, to simulate actual growth of the plants, a layer of fresh planting compound, of about 10mm, is spread across the base of the sample box. The pre-grown plants are then placed onto the fresh planting compound.

III. Results

Demolition by a water jet was carried out on both samples.

A. Sample 1

Soil was removed using a water jet. Jet pressure applied was held consistently low to prevent unwanted disturbance to the soil. Soil was removed at a rate of approximately 0.75mm/min for a surface area of 1,000mm×200mm or 150cm^3/min.
Roots structure exposed after 10mm of soil was removed was vast. This indicates that the duration of this sample was sufficient for roots growth. Exposed roots were approximately 2.5mm thick in diameter, of which covered about 20% of the exposed area (fig. 3).


Fig. 3 Initial exposure of roots

Further erosion revealed the main root of one of the plants of diameter about 12mm. This root terminated 15mm before it reached the membrane. Moreover, the secondary roots, of about 2mm diameter, also turned sideways when they reached the membrane as shown in fig. 4.


Fig. 4 Main root of one of the plants

From fig. 5, coverage of secondary roots on the membrane was about 15%. This shows that main roots did not force its way across a membrane; main roots will grow above and do not damage the membrane.

Fig. 5 Secondary roots spreading on membrane surface

Roots did not grow into the membrane at this area but did seem to grow into the liquid applied waterproofing material used to seal the edges of the sample box. However, there was no evidence of outright penetration as seen in fig. 6.

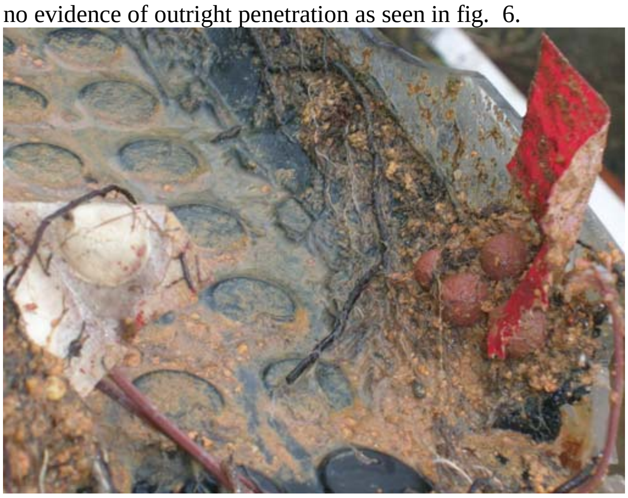

Fig. 6 Roots seemed to have grown into the liquid applied waterproofing at the edge

Further erosion reveals that there were some minor roots which seemed to have grown into the membrane (fig. 7).

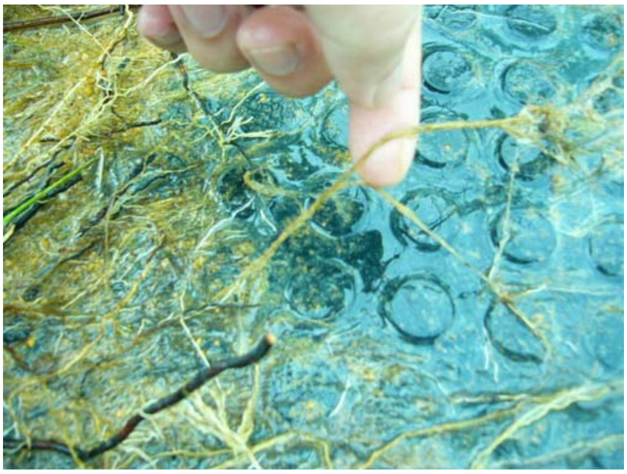

Fig. 7 Roots which seemed to have anchored on the membrane

From fig. 8, minor roots which seemed to have anchored on the membrane can be seen. The coverage of these roots was about 40%. Though at closer examination, there was no sign of damages, the long term effect of anchorage cannot be ignored.

Fig. 8 Roots left on the membrane after some erosion; the plants are removed whereas roots which have anchored on the membrane are cut from the plant

The liquid applied waterproofing was subsequently detached from the sheet membrane and it revealed that no root grew into the joint (fig. 9).

Fig. 9 Clean sheet membrane edges indicate no form of growth between the liquid applied waterproofing and sheet membrane

B. Sample 2

Soil was also removed with a water jet. Upon removal of the first 10mm of soil, substantial root structure was noticed. This again signifies extensive root structure. Further erosion of soil revealed that all the root structures were more well established than those in sample 1, indicating that there was good root growth and the artificial environment created for this sample was conducive for root growth. The root coverage was more than 50% throughout, which was more than sample 1 (15-20%), as seen in fig. 10.

Fig. 10 Vast root structures

However, the size of roots in this sample was significantly smaller than those in sample 1. This also indicates that though the duration of this sample was sufficient for the root system to grow, the roots might not reach the optimum growth size.From the fig. 11 below, although roots did not anchor in the membrane, it indicates prying action of the roots. This could be due to the improper application of the sealant during the setting-up stage; sealant was not applied to the edge of the joint. The other possibility is simply plant roots poses a challenge to waterproofing systems.

Fig. 11 Growth observed between joints of the membranes

When erosion was sufficient, individual plants, together with some soil, could be lifted. This indicates that was no anchorage of the plants onto the membrane. Furthermore, when observed from the bottom, roots could be seen, implying that roots have grown in and over the fresh plant compound lay below the pre-grown plants (fig. 12). Hence, there is sufficient evidence to indicate that the method of using pre-grown plants to accelerate the sample is viable.

Fig. 12 Roots growing through fresh planting compound

Subsequent erosion of the soil did not reveal other forms of damages inflicted on the membrane by the plant roots. Therefore, the membrane was preserved and studied under a microscope at a later time. Areas where there were significant amount of root growth were studied. These areas were isolated into sections of about 8×8mm. Fig. 13 shows the 2.5× magnification of the area.

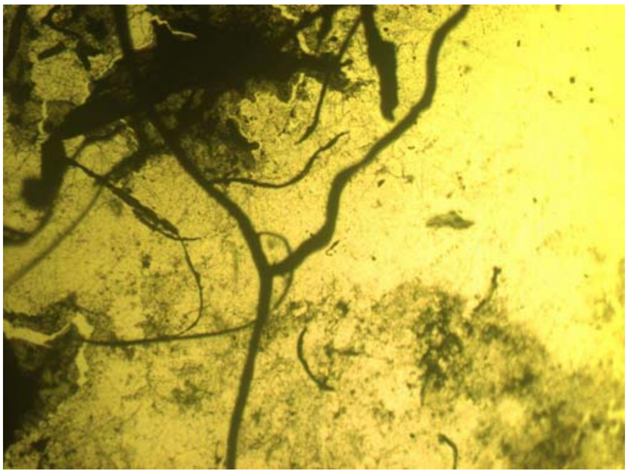

Fig. 13 2.5× magnification of typical area (traces of soil seen at top center of fig; algae seen at bottom left of fig)

Fig. 14 shows an area under magnification, focusing at different heights. The top fig. focuses on the root while the bottom fig. focuses on the membrane. This implies that as there was an inability to focus on both the membrane and the root, there was a substantial difference in the level of the root and the membrane. This indicates that the root has not grown deep into the membrane.

Fig. 14 20× magnification of typical area focusing on the root

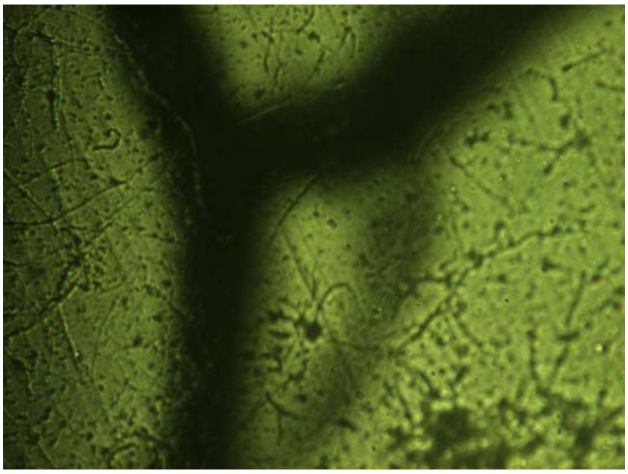

Fig. 15 20× magnification of typical area focusing on the membrane

To verify the above inference, the root is removed under a running tap. It was observed that though there was some staining of the membrane under the root growth, there was no root growth mark left on the membrane (fig. 16).

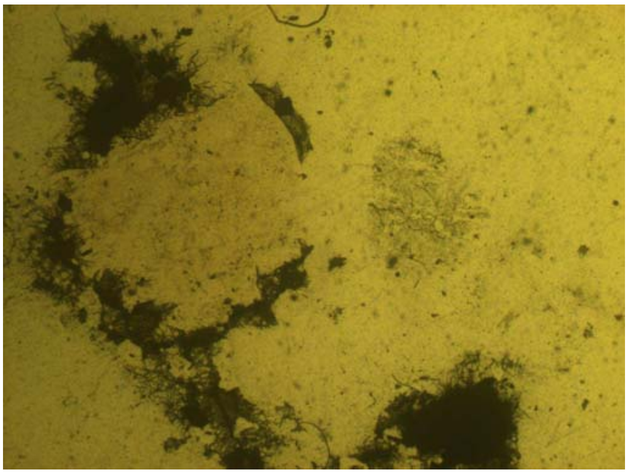

Fig. 16 2.5× magnification of typical area with root cleared

IV. Conclusion

From the study, both samples' waterproofing membranes were slightly damaged by plant roots. Though the damages were minor, the long term effects cannot be ignored; the damages done could be exponential and considering the duration of these experiments, root damage on waterproofing membrane is possible. Further studies are recommended for definite conclusion.

Comparing sample 2 to sample 1, though the root density of sample 2 is higher, the roots sizes were smaller. This is mainly attributed to the much shorter experimental period of sample 2. As the damages done to sample 1 was mainly on the surface of the membrane whereas those on sample 2 was to the joints, this may suggest different types of damages inflicted by different root sizes.

The difference between types of damages inflicted could also be due to the surface of the membrane, i.e. the surface of sample 1 membrane was slightly rough whereas that of sample 2 membrane was smooth. The roughness of membrane surface could have encouraged plant roots to anchor onto the membrane; a smooth surface deters roots from anchoring onto the membrane.

It can be established that the method of acceleration employed in sample 2 is feasible because:

1. the root density of was much higher than sample 1; and
2. there was significant root growth in the layer of fresh planting medium used.

Finally, one shortcoming established in the course of the experiment was that the FLL test relies heavily on visual inspection. It is nearly impossible to quantify any root damage. Therefore the result of the test will be subjected to the discretion examiner. Further studies exploring other means of assessment are recommended.

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