Environmentally Sustainable Structural Engineering

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Summary

Global deforestation is largely motivated by demand for commercial mature timber, a small percentage of available wood fibre in nature. The rest, in the form of small diameter timber (SDT), is mostly discarded because there is no simple, low-cost and technically sound connection method to enable its use as a premium structural material. The LPSA (light prestressed segmented arch) structural system provides this method and much more. It provides the engineering science framework for a sustainable structural engineering discipline based on SDT. For the first time, strength and behaviour of timber structures can be predicted through analysis. The LPSA also defines an environmentally sustainable construction technology that offers durable, lower-cost alternatives to both steel and concrete. Deforestation practices can be replaced by a regime of forest conservation that also creates a sustainable forest-based economy. Poverty alleviation, provision of dignified shelter and forest fire inhibition are some of the timeless consequences. LPSA modular forms enable cost saving simplifications in manufacture, transportation, assembly, maintenance and reuse. A unique feature of the LPSA slide-fit compression adhesion connection mechanism is harmless dynamic energy absorption and dissipation, creating unrivalled, durable solutions in earthquake-, hurricane- and flood-prone locations, worldwide.

Keywords: Bridges, buildings, deforestation, earthquakes, global warming, LPSA, poverty, sustainable development, sustainable engineering.

1. Introduction

Deforestation is a major contributor to climate change and consequent global warming. It is largely motivated by demand for commercial timber from mature trees. These constitute a small, non-sustainable percentage of available wood fibre. The remainder is in the form of small diameter timber (SDT) from younger trees. This inexhaustible natural resource hardly has any commercial value and is mostly discarded to become potential fuel for forest fires. Therefore, SDT is the key to solving the global problems of deforestation, forest fires and ensuring the environmental sustainability of wood as a construction material. The excellent physical and mechanical properties of SDT are well-known [1, 2], thanks to the natural growth ring structure. However, connection methods have been limited to skilled carpentry procedures of implanting metal plates at the ends of SDT members and fixing them by bolting or tying to the member. Figs 1 and 2 respectively depict such procedures, advocated in the US by the Forest Products Laboratory [3] and in Europe in a European-funded multi-national project [4] that adopted Delft University's method [5] shown in Fig 2.

Fig 1. Common SDT connection method.

These connection procedures belong to a pre-computer era of linear beam theory where they would be modelled as simple pin connections. In the context of contemporary stress analysis, damage caused to the relatively young wood fibre, the natural cracking as the wood seasons and the

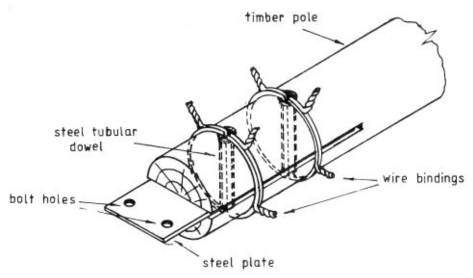

Fig 2. An "improved" version of the SDT connection method of Fig 1

metal/wood interaction and stress concentrations are all beyond engineering modelling and quantification. Even the simplest frame with these planted connections is beyond the capacity of any meaningful analysis. The high cost of such procedures and the impossibility of mass production rule out any commercial applications.

Futility of these connection methods has been vividly demonstrated in real life. The SDT connection procedure of Fig 1 belongs to a large public building in the City of Minnetonka, Minnesota, USA. When the roof developed a slight leakage, the engineers who had designed the structure declined to certify it, claiming that it had not been designed for roof leakage. As a result, insurance was denied and the City administration had to demolish the building in 1997.

In the light of these facts, the LPSA connection method represents a generational leap forward and an important major development in engineering analysis and practice. The analysis "black box" imposed by SDT connection methods is simply abolished by the LPSA system. SDT is introduced as a superior alternative to structural sawn timber that can also compete with both steel and concrete.

2. The LPSA (Light Prestressed Segmented Arch) Structural System

The core of the LPSA concept is a connection method based on simple physics. A typical engineering structure would consist of longitudinal "segments" joined together via "connector" nodes and the whole assembly is then held together by a tensioning system. Although the concept is independent of the materials used, emphasis here is on SDT segment members, due to the impressive environmental, economic, social and commercial realities about SDT, worldwide.

2.1 The connection method

In most cases, the only processing needed to convert a freshly cut small tree trunk into a segment member in a LPSA structure is: (a) cutting accurately and squarely to length and (b) rounding for short distances along the ends to slide-fit into tubular sockets on connector units.

The following pictures of a recent bridge in Iowa, USA, depict the simple LPSA jointing and assembly procedures.

Figs 3, 4 and 5. LPSA bridge in Iowa, USA

The bridge was assembled by local Iowa school children as a community environmental education exercise led by SustainableScience.org Inc. Fig 3 shows the SDT posts with their rounded ends being inserted into thin-wall connector sockets. The ends are squarely cut so that they have uniform seating inside the sockets to avoid stress concentrations. Fig 4 depicts two galvanised connectors being easily carried by a student. Fabrication of the connectors is both simple and accurate. The completed structure is shown in Fig 5. More details and pictures about this bridge appear in [6].

The following pictures show a LPSA research prototype of a building structure spanning 8 m. Over a five-year period, it delivered valuable data about SDT properties under long-term loading, see [2].

Figs 6, 7 and 8. LPSA building structure in the UK.

A typical connector unit is being mounted in Fig 6 as the light LPSA frame stands unsupported. Fig7 shows the completed unsupported frame before tensioning. Fig 8 shows the connection arrangement within the tensioned and covered structure. The single central tensioning strand is behind the LPSA post in Fig 8. All used posts were purchased as fencing material. The connector tubes were recycled from scrap yards.

In comparison with the connections of Figs 1 and 2, the LPSA method offers minimal processing that does not interfere with the natural growth-ring structure of SDT. Low-cost mass processing of SDT posts becomes a reality for the first time. Moreover, it can be tailored to suit both developed and developing regions of the world. This is equally true for fabrication of the connectors.

The LPSA connection method produces some unique structural features. The slide-fit mechanism allows SDT movements within the sockets. Therefore, resulting structures can absorb and harmlessly dissipate, through local rigid-body displacements, external dynamic energy induced by earthquakes, hurricanes and flooding. Moreover, on removal of tensioning, the whole structure can be easily dismantled for repair or re-use if needed. Mostly, individual SDT members can be replaced without the need to dismantle the whole structure. Any and all conventional engineering structures can be reproduced in a LPSA forms if practical requirements allow.

2.2 An engineering and computational mechanics basis for round timber engineering

With the analysis “black box” imposed by carpentry connection methods of Figs 1 and 2 removed, it is possible to connect up timber engineering with major advances made in continuum and computational mechanics over recent decades. SDT posts are treated mainly as compression members, pending more research. Detailed stress analysis of the crucial connector units means that, for the first time, the strength and behaviour of a timber structure can be predicted in advance. Using nonlinear elastic-plastic, large deformation finite element analysis, with conservative tensioning levels, it was found that the foot bridge in Figs 3-5 is capable of carrying highway loading according to US standards. Analysis results are to be published separately in the near future. As an initial demonstration of this capacity, three vehicles were parked along its 19.5 m span [6]. It is to be noted that this analysis breakthrough does not apply to conventional timber structures.

2.3 LPSA technology awards

In 2010, this institute won the *sustainable technologies* category award in the *Create the Future Design Contest*. The contest attracted entries from 52 countries and was organised in the USA by the *Tech Briefs Media Group*. The awarded entry was the bridge shown in Figs 3-5 above. In 1990, three LPSA prototype structures, one of which is depicted in Figs 6-8 above, won the top business invention award in a UK national invention competition organised by the UK's *Design Council* and funded by the *Toshiba Corporation*. The project also attracted public research and development funding both in the UK and the USA. More information can be found on the Institute's web site [7].

3. Sustainable development and poverty alleviation out of halting deforestation.

Adding value to SDT, a vast natural but hardly marketable resource, creates environmentally sustainable wealth. Forest destruction through clear cutting does not. When SDT becomes the principal forest product, rather than mature sawn timber, a forest preservation regime evolves. This regime could provide an engine for self-funded sustainable development. Moreover, the LPSA system could provide the technological tools to develop community-based manufacturing and construction industries and small businesses. Using locally available resources, it could also provide low-cost, self-build, durable shelter for people, livestock and produce that would withstand the violent elements of nature.

4. A LPSA technology transfer plan

SustainableScience.org Inc. is a non-profit engineering research, design and innovation institute and a tax-exempt charity. It was incorporated in the USA in 1999. It has a specific mission to advance environmental sustainability as a tool of development through science, hence the LPSA system. This mission is best achieved through communities, rather than through direct commercial business development. This is because sustainability cannot be achieved by individuals, groups or even governments. Society as a whole must be fully involved.

Two parallel and interacting routes for LPSA technology transfer are envisaged:

1. University research and instruction programs to transfer new knowledge and technical know-how developed over many years.
2. Community based training and actual development projects, especially in poverty stricken rural areas in developing countries. Community-based technology commercialisation would be a rewarding by-product of this route.

In a low-tech version of this plan, a small technical team, supported by a simple village workshop facility, would teach and supervise a village community in a poverty stricken region to build their own durable homes and other amenities and even start small businesses using locally available resources. In the context of the LPSA system, even bundles of reeds would substitute for SDT in constructing significant building structures.

This Institute is ready to cooperate with universities, public- and private–sector community organisations worldwide along these lines. The Institute has posted on its web site [7] a link to its European Project Proposal, with a view to forming an international consortium that would apply for European funding.

5. Conclusions

The LPSA structural system is a basis for a sustainable structural engineering discipline via SDT, an inexhaustible, renewable resource. For the first time, strength and behaviour of timber structures can be predicted by analysis. Considerable simplifications and savings are achieved in manufacture, transportation and assembly of very durable building and bridge structures. Adding value to SDT creates wealth and hence a basis for a sustainable economic sector that would alleviate poverty. It also provides an attractive, logical alternative to halt deforestation practices, a major source for global warming. For maximum benefits to society, LPSA technology transfer and commercialisation must be community-based.

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