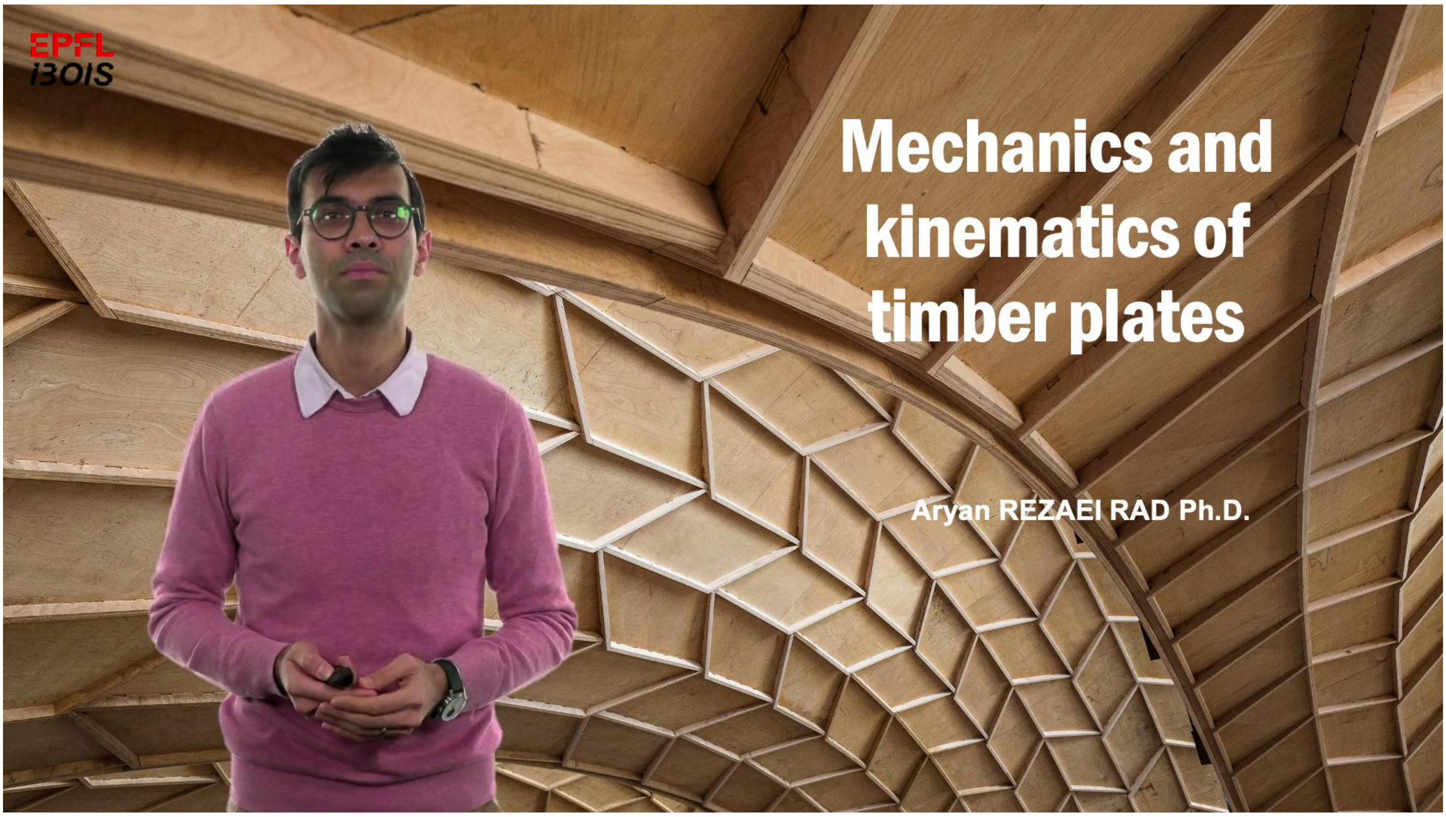
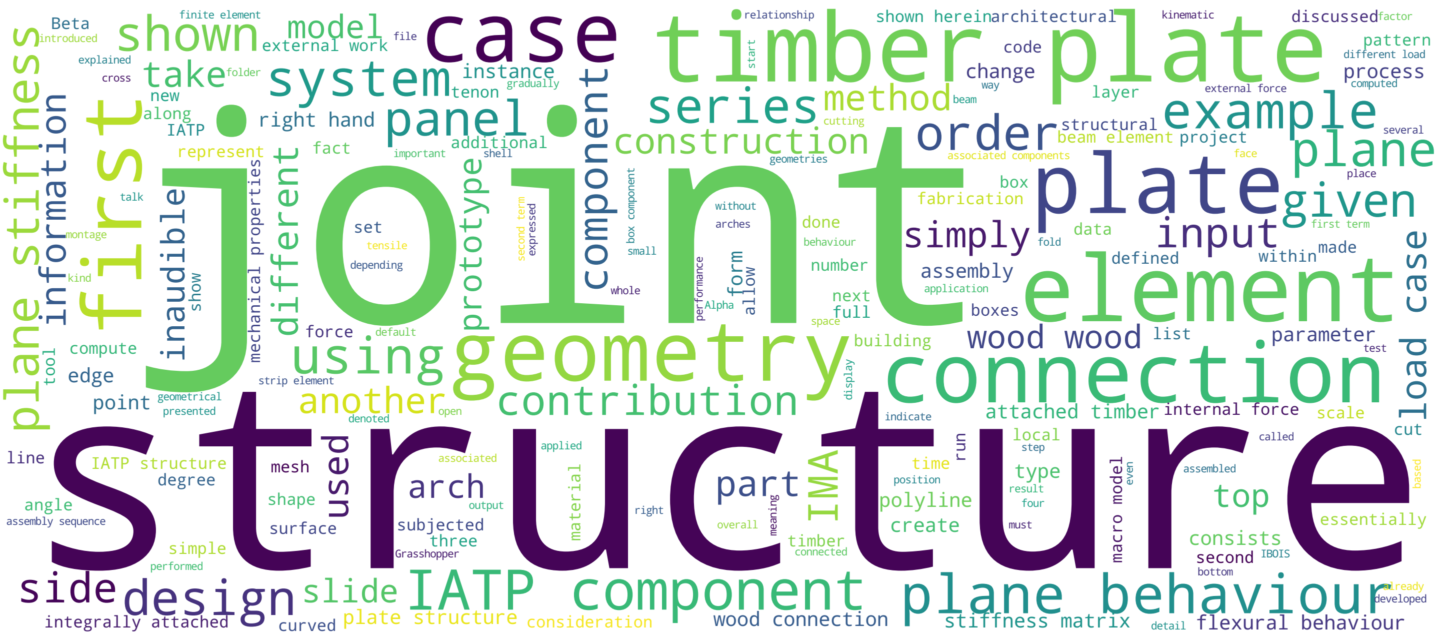




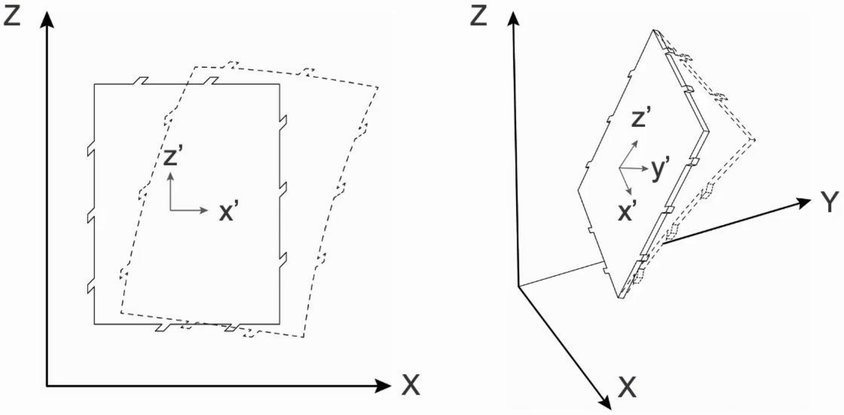
Search MOOC

Video

EPFL

Kinematics of components

- An IATP component consists of timber plate and edgewise IMAs.
- The behavior of an IATP component is governed by:



In-Plane behavior **Out-of-Plane behavior**

Advanced Timber Plate Structural Design

Aryan Rezaei Rad

After studying the joint behaviour, the component behaviour of IATPs is presented, and consequently, the introduction of the element formulation is discussed in this section. To understand the behaviour of integrally attached timber plate structures, we should first study the kinematics of such systems and the associated components. The kinematics of IATP components are first studied. Given the primary focus on the global, or let's say on the structural scale, the overall behaviour is deemed to be governed by the in-plane behaviour and the out-of-plane response of the IATP components. These two cases are graphically illustrated here. May I remind that an IATP component consists of timber plates and edgewise integral mechanical attachments that are centred around the perimeter of that timber plate.

Notes

Summary

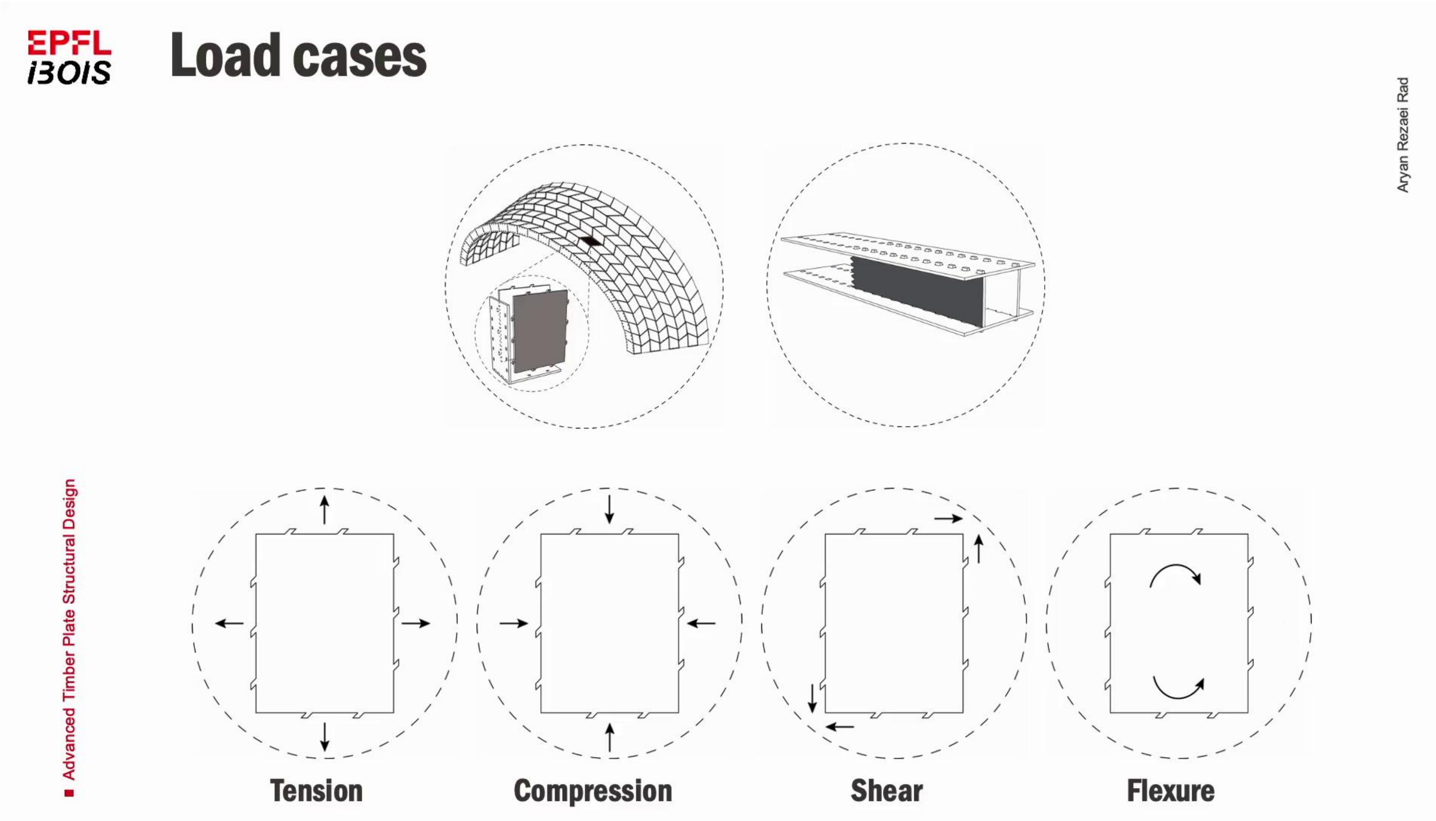
0m 04s

Okay, let's talk about the in-plane and out-of-plane behaviour separately.

Notes

Summary

1m 08s



First, regarding the in-plane behaviour, some IATP structures with free form or with also standard forms are shown herein. The associated components that can be subjected to the in-plane behaviour is also bolded or highlighted here. Okay, each component that you see here can be subjected to different load cases such as tensile in both directions, compressive loads, again in both directions, local X, local Z, shear loads, and finally flexural moments. These are the four different load cases that can potentially exist in the in-plane behaviour of an IATP component.

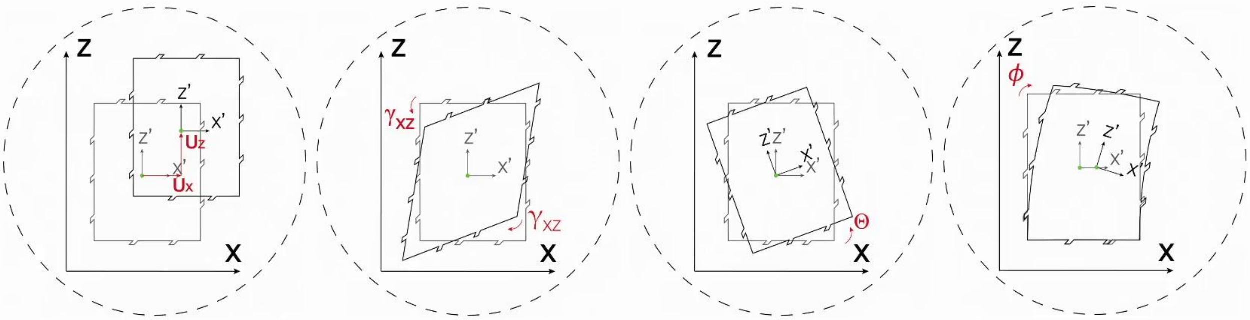
Notes

Summary

1m 13s

Displacement and force field

Aryan Rezaei Rad



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Displacement field → **Corresponding force**

$$D_{IP} = \{U_X \quad U_Z \quad \gamma_{XZ} \quad \Theta \quad \phi\}^T$$

$$F_{IP} = \{P_X \quad P_Z \quad P_{XZ} \quad M_{Y,rgd} \quad M_{Y,flx}\}^T$$

Now, given these load cases, given this consideration, an integrally attached timber plate demonstrates rigid body translation, shear behaviour, rigid-body rotation, and flexural deformation. Displacement field, denoted as D_IP accordingly, consists of U_X, U_Z, Gamma_XZ, capital Theta, and Phi. Now, given the displacement field that I've already explained here, the corresponding force system defined as F_IP can be shown herein. F_IP consists of P_X, P_Z, P_XZ, M_Y rigid, and M_Y flexural.

Notes

Summary

2m 03s

EPFL IBOIS

Virtual work principles

Aryan Rezaei Rad

$$\delta W_{external} = \delta W_{internal}$$

A set of virtual displacement on the external force

Compatible virtual deformations on the element forces

$$\delta D_{IP}^{T} \, . \, F_{IP} = \boxed{\sum_{j=1}^{m} \left[\delta u_{IP,j}^{\;T} . f_{IMA,IP,j} \right]} + \boxed{\int_{V} (\delta \varepsilon_{z'}^{\;T} . \sigma_{z'} + \delta \gamma_{z'}^{\;T} . \tau_{z'}) dV}$$

$$F_{IP} = \sum_{j=1}^{m} \left[(B_{IP})^{T} . f_{IMA,IP,j} \right] + \begin{Bmatrix} \int_{L} N(z')dz' \\ 0 \\ \int_{L} V(z')dz' \\ 0 \\ \int_{L} M_{y'}(z')dz' \end{Bmatrix}$$

Advanced Timber Plate Structural Design

Therefore, we can compute the in-plane stiffness by applying the virtual work principle. The external work is done by a set of virtual displacement on the external forces, and accordingly, internal work is done by compatible virtual deformation on the element forces. The relationship between the internal and external work are shown herein. The first term in the right hand of the equation shown in red shows that the work done by the IMAs, and this actually consists of u_IP, which indicates the internal deformation, and f_IMA, which indicates the internal forces. Also, the second term in the right hand of the equation shows the work done by the plate. It consists of axial and shear contributions. In fact, the integration computes the virtual section work over the element heights. After the mathematical calculations, the virtual terms are eliminated and the applied loads are expressed in terms of internal forces as you see here in this slide.

Notes

Summary

2m 56s

Virtual work principles

Aryan Rezaei Rad

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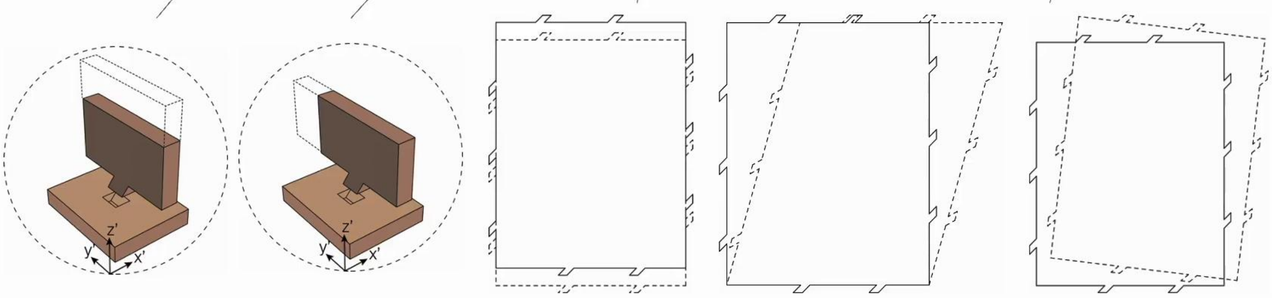
$$K_{IP,\,Plate} = \sum_{j=1}^{m} \left(B_{IP,j}^{\;T} . \begin{bmatrix} K_{IMA,tns} & 0 \\ 0 & K_{IMA,edg} \end{bmatrix} . B_{IP,j} \right) + \begin{bmatrix} K_{Plate.ax} & 0 & 0 & 0 & 0 \\ & 0 & 0 & 0 & 0 \\ & & K_{Plate.Shr} & 0 & 0 \\ & sym. & & 0 & 0 \\ & & & & K_{Plate.flx} \end{bmatrix}$$



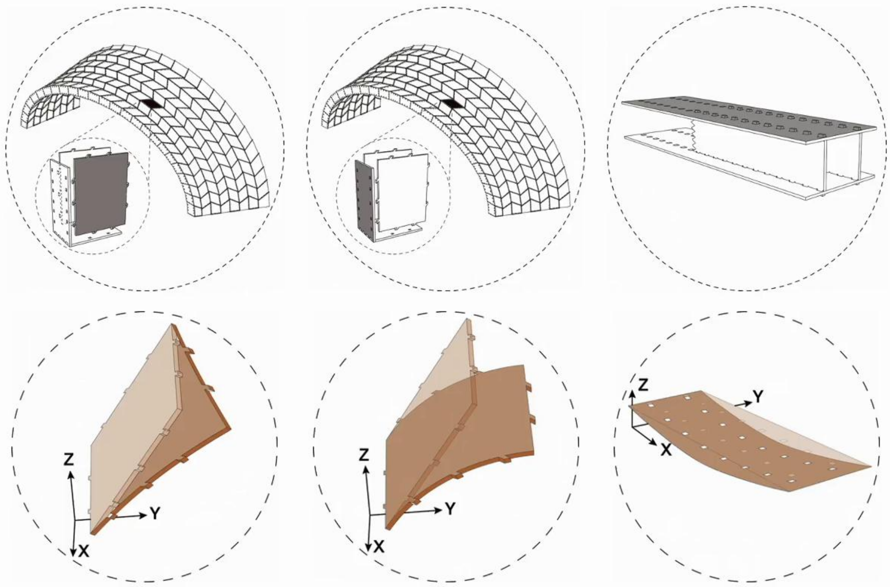
Okay, having both force and deformation, the in_plane stiffness of the IATP component is calculated. The first term indicates the contribution of the IMAs, and the second term indicates the contribution of timber plates. In this slide, the mechanical properties associated with the in-plane stiffness of the IATP component is demonstrated. The contribution of IMAs, as we've already discussed before, includes the tensile and of course the edgewise behaviour, and these data, load deformation behaviour and mechanical properties are coming from the experimental tests, and the contribution of the plate itself includes axial, shear, and finally flexural behaviour. The axial behaviour is denoted as K_Plate.ax, K_Plate.Shr as the shear behaviour, and K_Plate.flx as the flexural in-plane behaviour of timber plates.

Notes

Summary

4m 16s

Load cases

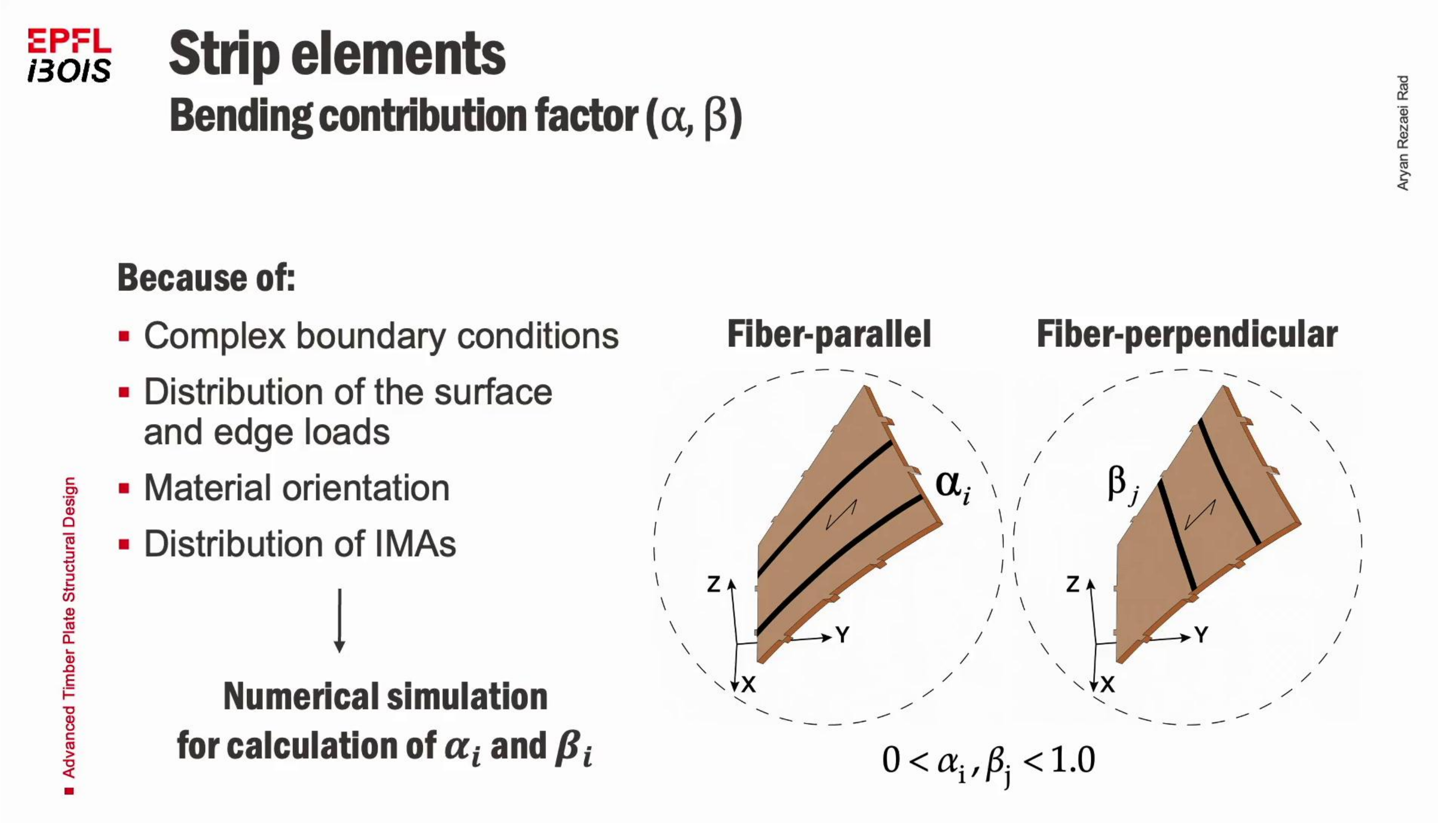


Regarding now the out-of-plane behaviour as the second assumptions we had in order to characterise the kinematic of integrally attached timber plates, again, some IATP structures in a global scale and their associated components that can be potentially subjected to out-of-plane loads are shown in this slide. These plates are already highlighted. Each IATP component, if we extract it, can be subjected to normally two load cases. The first one would be unixial load cases, as you see herein. They are bent under single axis. The second category is by axial bending moments. For example, in this case, elements are subjected to local X and local Y.

Notes

Summary

5m 34s



Given this consideration and showing the out-of-plane applied loads here in M_x', M_z', and P_y', an IATP component demonstrates flexural deformations. In other words, flexure is recognised as the main kinematic behaviour in the out-of-plane response. The flexural behaviour can be about local X' and/or local Z' axis as it is already shown in the right-hand picture of this slide. Meanwhile, given that the plate thickness is small relative to the perimeter dimensions, the out-of-plane behaviour of IATPs is characterised using multiple beam elements. The beam elements which represent a strip of the plate are along the directions parallel and perpendicular to the fibers. For each strip element, an out-of-plane bending contribution factor is assigned. This factor is defined as Alpha and Beta for the fiber parallel and for fiber perpendicular strips respectively. Alpha and Beta are affected in the out-of-plane stiffness matrix of the IATP element, and will be shown in the next slides. Multiple parameters affect these factors. For complex assemblies with large number of degrees of freedom, different boundary conditions and distribution loads, a numerical simulation is required to compute Alpha and Beta.

Notes

Summary

6m 24s

Virtual work principles

Aryan Rezaei Rad

$$\delta W_{\text{external}} = \delta W_{\text{internal}}$$

A set of virtual displacement on the external force

Compatible virtual deformations on the element forces

$$F_{OP} \,.\, \delta D_{OP} = f_{OP} \,.\, \delta u_{OP}$$

$$F_{OP} = B_{OP} \,.\, f_{OP}$$

$$K_{Strip} = \frac{\partial F_{OP}}{\partial D_{OP}} = \frac{\partial}{\partial D_{OP}}(B_{OP}{}^{T}.f_{OP}) = B_{OP}{}^{T}.\frac{\partial f_{OP}}{\partial u_{OP}}.\frac{\partial u_{OP}}{\partial D_{OP}} = B_{OP}{}^{T}.K_{basic}.B_{OP}$$

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Now, first to compute the out-of-plane stiffness similar to what was explained for the in-plane behaviour, the virtual work principle is applied. The external work is done by a set of virtual displacement and the external forces as it was explained for the in-plane behaviour, and the internal work is similarly done by compatible virtual deformations on the element forces. Now, the relationship between the internal and external works are shown herein, and after eliminating virtual terms, it is shown that the external force is expressed in terms of the internal forces with a transformation matrix, B_OP, having both force and deformation. The out-of-plane stiffness of each strip element is calculated, denoted as K_Strip in this slide. Also, K_basic that you see here is the basic stiffness matrix of a beam element. Basic stiffness matrix is the inverse of the flexibility matrix.

Notes

Summary

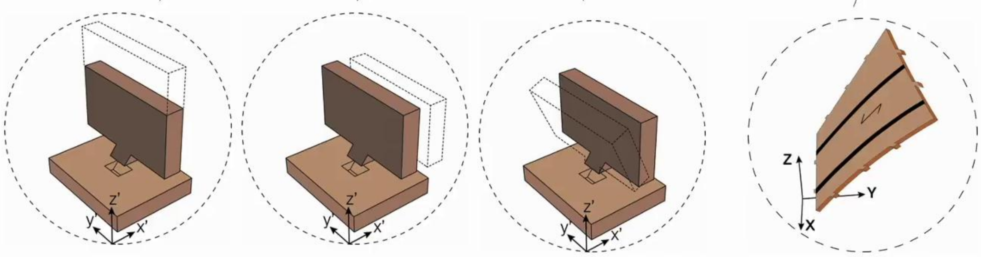
8m 11s

Virtual work principles

Aryan Rezaei Rad

Advanced Timber Plate Structural Design

$$K_{OP,\,Plate} = \sum_{j=1}^{m} \left(B_{OP,j}^{\;T} \cdot \begin{bmatrix} K_{IMA,tns} & 0 & 0 \\ 0 & K_{IMA,flt} & 0 \\ 0 & 0 & K_{IMA,flx} \end{bmatrix} \cdot B_{OP,j} \right) + \sum_{i=1}^{n} \alpha_i \cdot K_{strip,i} + \sum_{j=1}^{m} \beta_j \cdot K_{strip,j}$$



Calculating the stiffness of the strip element, now the out-of-plane stiffness of the IATP component can be calculated. Again, and similar to what we discussed before, the first term in the right-hand side of the equation indicates the contribution of IMAs, and the second term of the equation in the right-hand side of the screen indicates the contribution of the plates. Given the stiffness matrix, here, the mechanical properties associated with the out-of-plane stiffness of the IATP component is demonstrated. The contribution of the IMAs, as we discussed before, consists of tensile, flat-wise, and flexural behaviour. They are denoted as K_IMA,tns as a tensile, K_IMA,flt as a flat-wise, and K_IMA,flx as a flexural behaviour. The contribution of timber plates includes flexural behaviour along the fiber parallel and fiber perpendicular directions. Here, exactly as you see, the out-of-plane contribution factors are Alpha and Beta, are reflected in these stiffness matrix.

Notes

Summary

9m 28s