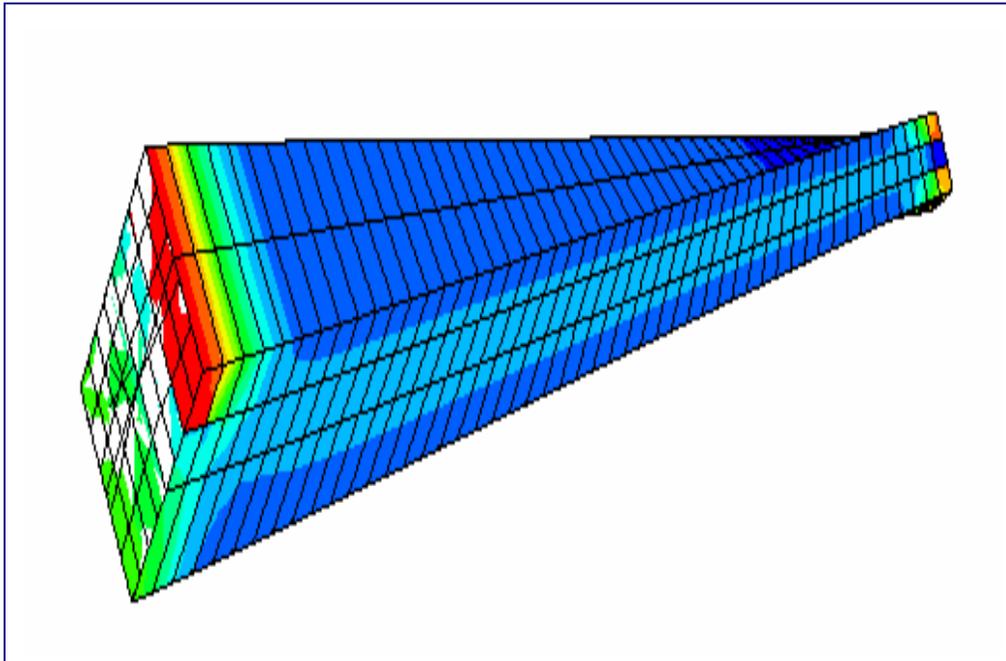# CHALMERS

Modelling distortion in partition walls as a result of twist in studs

Master's Thesis in the International Master's Programme Structural Engineering

M.YOUSUF SABAH
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Department of Civil and Environmental Engineering
Division of Structural Engineering
Steel and Timber Structures
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Geometry of a partition wall in ABAQUS

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ABSTRACT

Two characteristics of wood are that its behaviour is strongly orthotropic and that it is very sensitive to variation in a moisture. In addition, wood is characterized by variation in its properties from the pith to the bark. Further important property of wood affecting its behaviour is its spiral grain. Timber in general changes its shape due to variations in a moisture content. In Scandinavia, the producers of timber normally dry timber to the moisture content (MC) of 18%. In addition to this after the construction of the wall structure, stud may distort as a result of further drying in the structure and these studs finally reach about 8% MC. It is therefore important to produce and deliver timber products dried to the appropriate MC as it affects the twist to be calculated. In the present thesis, a finite element method is used to simulate deformations and stresses in partition wall.

The role of the material properties remains important despite of the many factors in the design of the timber partition wall structures. A three-dimensional model for the numerical simulations of deformations and stresses in wood during different conditions is described. Here the partition wall is modelled using a commercial FEM analysis software, stud as a solid timber and cladding as gypsum with connection type as spring. Wood is assumed to be an Engineering constants material with differences in properties between the longitudinal, radial and tangential directions regarding the stiffness parameters. When it comes to cladding it is assumed as an isotropic material.

The three-dimensional model used for analysing the shape stability of sawn timber was implemented in a finite element program. These simulations yield information on unfavourable deformations and stresses that can develop during the slow drying process in-service conditions. The finite element model is also used to clarify how the material properties and the internal structure affect stiffness properties in sawn timber. The influence of the stiffness parameters, the spiral grain and the annual ring orientation are of particular interest.

The results of the work show that it is possible to link the numerical model with the experimental test model to design a well-structured timber partition wall. The knowledge obtained can contribute to more effective use of the raw material through allowing studs with properties resulting in poor shape stability to be sorted out.

Keywords: Connection, timber, finite element method, simulation and distortion.

II

Contents

Preface

This master thesis project work part of the International Master's Programme in Structural Engineering has been carried out at the Department of Structural Engineering, Chalmers University of Technology. The work has been pursued at the department, with the continuous support from our supervisor Magnus Bäckström. This thesis concludes the authors' Masters of Science Degree in Structural Engineering, at Chalmers University of Technology.

Professor Robert Kliger, the examiner, has provided assistance and invaluable insights during the course of this project work.

This is part of research work of Magnus Bäckström PhD project, "Shape stability of wall structures- influence of dimensional stability of built in timber studs." The initiator, as well as our supervisor of this thesis work; Magnus has been a fountain of information regarding the modelling and theory of the project. Magnus has helped considerably through his clarity, enthusiasm and his unselfish willingness to assist while directing this project.

For guidance regarding Abaqus software we like to thank Sigurdur Ormarsson and John Eriksson for their help and support.

Our opponents, Ching Chun Yuen, Robin and Godwin George Ogwemoh, have continuously assisted with the development of this thesis and we thank them wholeheartedly.

Finally, we would like to thank our families, who have persevered with us through our studies at Chalmers.

Gothenburg April 2005

M.Yousuf Sabah & Srinivas Rao Kagitha.

Notations

The followings notations and symbols are used in this thesis:

General notations

$[\,]$	Matrix
$[\,]^T$	Transpose of matrix
$\tilde{\nabla}$	Matrix differential operator
$\int\limits_S (\ )ds$	Integration over the surface
$\int\limits_V (\ )dV$	Integration over the volume

Roman upper case letters

$\tilde{C}$	Compliance matrix in the local coordinate system
D	Constitutive matrix in the global coordinate system
$E_L \ \ E_r \ \ E_t$	Elastic modulus in the orthotropic directions l, r and t
$G_{Lr} . G_{Lt} \ \ G_{rt}$	Shear modulus in the orthotropic direction l, r and t
N	Shape function matrix
$\dot{P}$	Column matrix of mechanical local rate
Q	Projection vector of the vector N on the pith direction

Roman lower case letters

a	Column matrix of nodal displacement
$\dot{a}$	Column matrix of nodal displacement rate
f	Column matrix of loading
$\dot{f}$	Column matrix of loading rate
f_b	Body force vector
f_x^b , f_y^b , f_z^b	Body force in global direction
$\dot{f}_b$	Body force rate vector
l, r, t	Unite vector in the local coordinate system
t	Traction vector
u_x, u_y, u_z	Components of the displacement vector
v	Vector of weight functions
f_y	Yield stress
$f_{u.k}$	Tensile strength

Greek letters

ε	Column matrix of total strain in the global coordinate system
$\dot{\varepsilon}$	Column matrix of total strain in the global system
θ	Spiral grain angle
σ	Column matrix of stresses in the global system
ϕ	Conical angle

1 Introduction

1.1 Background

In the modern era wood product is one of the most important materials for furniture and construction industries. Small deformations and distortion in wood material can completely ruin the intended function for a specific purpose. So it is very important factor to be considered and analysed before a structure is constructed.

Distortions in timber materials are caused by moisture variations. This phenomenon occurs when the timber materials are moved to a new environment. As wood is an anisotropy material, when it is dried the moisture content will vary within the specimen and during this process, some part of it will shrink while the others will not. These variations in shrinkage within the specimen give rise to constraints and stresses that will cause the deformations in the specimen.

Considerable distortions in timber materials such as twist, bow, crook and cup occur when wood materials are exposed to moisture variation. The distortion of wood products cause serious problem and makes the products less attractive to the customers.

The experimental study made by Bäckström (2004) shows the behaviour of a wall structure made of studs, gypsum, cladding and connecting screws when exposed to moisture variations. The study also comprises an examination of the behaviour of different components of the wall system including the screws that connect the cladding with the stud and the forces acting on the stud.

1.2 Aim and limitation of this study

The aim of this study is to find out the deformation behaviour of the studs in a partition wall structure when it is exposed to varying moisture content. By assembling the gypsum cladding on the wall structure, the deformation behaviour of the studs on both single cladding and double cladding are studied with the use of finite element simulation commercial software Abaqus version 6.3, (Hibbitt, Karlsson & Sorensen, Inc 2002).

This thesis is divided into three principal sections. The first section is the literature study, the second and the most important one is the finite element modelling of the wall structure and the last one but not the least, comparing the results with the experimental results of Bäckström.

By comparing the results from the experimental study by Bäckström (2004) with result from FE-simulations run on the partition wall model, verification of the simulations could be made. Timber materials and its properties are limited to Norway spruce (P*icea abies*) unless otherwise stated.

1.3   Method

Due to the complex structure of wood, it is difficult to predict whether timber products will have good shape stability. However, numerical simulations can be used to study the shape stability of wooden structures. This present thesis work consists of literature studies, design of the partition wall by using commercial finite element analysis software, and comparing the results with the results from experimental study of Bäckström (2004).

The process starts with an observation of a stud and its behaviour when twisted with a known angle, which is modelled in Abaqus. A partition wall with the studs and the gypsum claddings is modelled in Abaqus and its behaviour is recorded with the same angle of twist as in the case of a single stud. The outcome of the results in the case of the complete partition wall is compared with the test results from the experiments conducted by Bäckström (2004).

The circle process (treating model with different sets of material properties and different sets of couple forces) with repeating examinations and evaluation is typical for the development work and gives feedback for the future work. Progress in small steps results in a goal with concrete functions, which is characteristic for the process. Other important parts for development work are discussions, evaluation and experience exchanges. This thesis is therefore based on literature studies, interviews, information research, comparison with the experiment results and finally own conclusions.

2 Wood and timber structures

2.1 General view of wood

Wood is a very important material for the construction industry. To know about the physical behaviour of the wood under different circumstances, the understanding of the structure of wood is important.

Wood is a natural organic solid material, which is composed of hydrogen (H), oxygen (O) and carbon (C) forming cellulose, hemicelluloses, lignin and extractives in polymeric chains, see Figure 2.1. Wood is an anisotropy material due to the belonged shapes of the wood cells and the oriented structure of the cell walls. Wood has different structural, mechanical and physical behaviour in different directions.
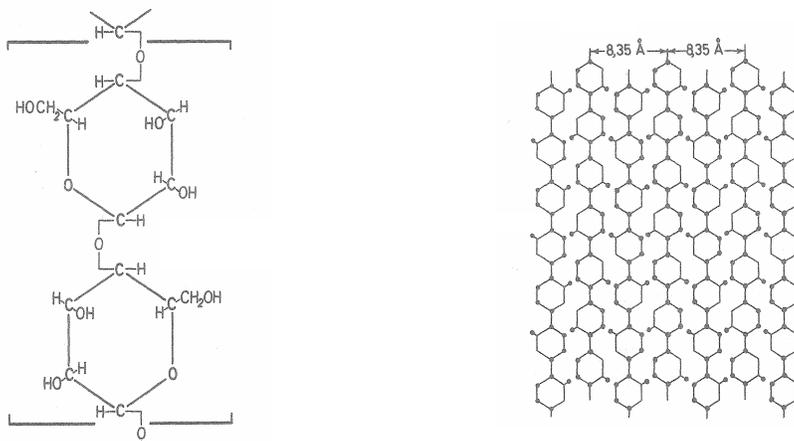
Figures 2.1   Basic molecular constitution (Burström, 2001).

The structure of the cell walls and the aggregation of cells to form the wood are very important for the properties of wood as engineering material. The ultra structure level of the cell wall provides the explanation of why shrinkage and swelling of wood is normally 10 to 20 times larger in the transverse direction when compared to the longitudinal direction. The microstructure of clear wood holds the key to understanding why wood is   20 to 40 times stiffer in the longitudinal direction than in the transverse direction. The macrostructure of wood including knots; fibre angle etc. explains why tensile strength along the grain may drop from more than 100 N/mm^2 for clear wood to less than 10 N/mm^2 for structural timber of low quality (Hoffmeyer1995).

Wood is obtained mainly from two broad categories of plants commercially known as hardwoods and softwoods. Observation of wood without optical aids shows not only differences between softwoods and hardwoods, and differences between species, but also differences within one specimen, for example sapwood and heartwood, early-wood and latewood, the arrangement of pores and the appearance of reaction wood. All these phenomena are the result of the development and growth of wood tissues.
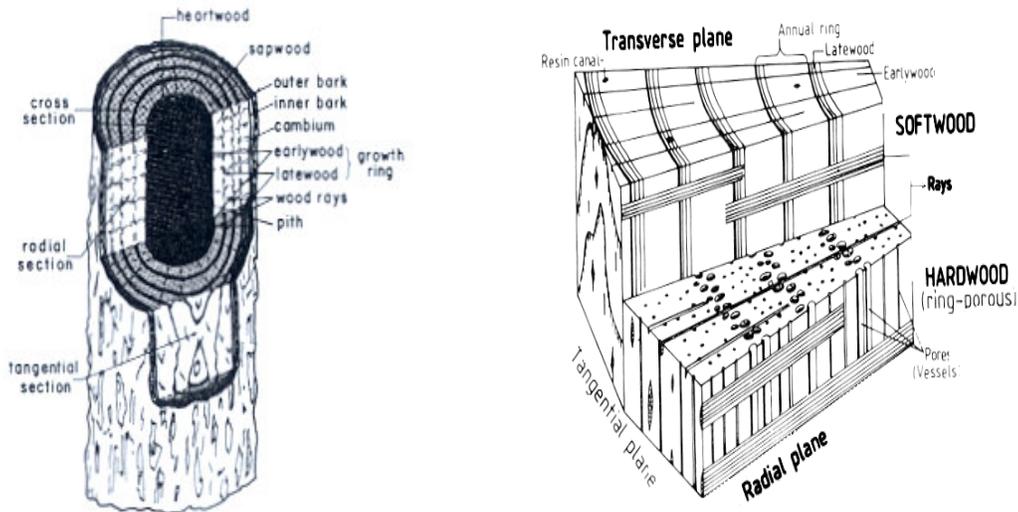
Figure 2.2   *a) The structure of wood from micro to macro making a stem (Bodig and Jayne, 1982).*

b) Models of Softwood and a Hardwood block showing the main Planes for anisotropy (adapted from Fengel and Wagener, 1984).

2.2 Timber and its properties

Wood is a natural resource that is widely available throughout the world. With proper management, there is a potential for an endless supply of timber and other wood-based materials. Wood material that is used for construction purpose is called timber. Timber is a live material with anisotropy material properties. In a piece of wood, you can see lines going in one direction; this direction is referred to as "with the grain". The wood is stronger with the grain than "against the grain". This property changes with the environmental conditions like moisture content, temperature, decay and insect damage. Mechanical properties of wood increase as wood dries from the fibre saturation point (moisture content of about 30%) to a moisture content of 10 to 15%. For clear wood mechanical properties of wood continue to increase as wood dries below 10 to 15% moisture content. Strength and stiffness decrease when wood is heated and increase when cooled. The temperature effect is immediate and reversible for short heating durations. Wood is vulnerable to decay and insect damage in moist, warm conditions. Decay within a structure cannot be tolerated because strength is rapidly reduced in even the early stages of decay. If the warm, moist conditions required for decay cannot be controlled, then the use of natural decay resistant wood species or chemical treatments is required to impede decay. Finally load duration has also a significant effect upon strength and deformation. Duration of load is exponentially related to stress, and ultimate stress is exponentially related to rate of loading. Rate of loading seems to have greater effect on strength of green wood than

on strength of dry wood, particularly in bending. Shear stresses also have a greater effect on the strength of wood that in turn depends on applied load.

For example, in a partition wall, the bottom and top plate, studs and noggins are made of timber. As the timber is very sensitive to climatic conditions such as relative humidity, it can easily change its shape. In the partition walls, the bottom and top plates are very well fastened to stiffer components of the building and the structure become more stable to the distortion. But the studs do not have such kind of support and that is the main problem for the shape stability of partition walls (Kliger et al. 1994). Timber is a natural material whose strength and stiffness vary depending on the angle between load and grain. It is strong and stiff parallel to the grain and vice-versa in perpendicular direction. However, a moisture content has a large effect on strength and stiffness of timber.

2.2.1 Influence of moisture and shape stability

As timber is made of natural material, it has different properties in different directions. The strength of wood parallel to grain is much higher than strength perpendicular to grain. For example: the tension strength of wood parallel to the grain is 40 times greater then the tension strength perpendicular to the grain.

As the timber is a hygroscopic material (literally "water seeking" is one that readily absorbs water usually from the atmosphere), the moisture content depends on the surrounding climate and changes according to relative humidity (RH). The equilibrium of moisture content of wood material is not only depending on the relative humidity but also on whether the equilibrium moisture content is reached during adsorption or desorption. This phenomenon is called the hysteresis effect (Bäckström 2004).
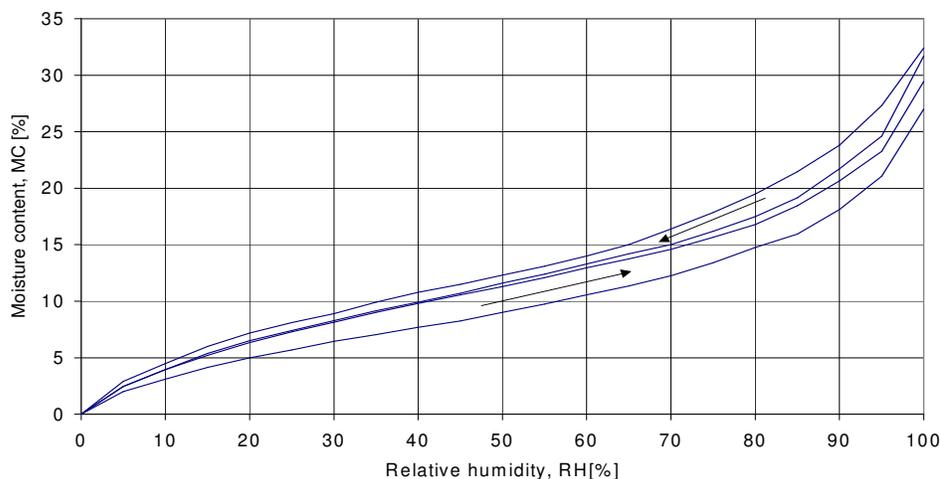

Figure 2.3   Isotherms with variation areas for desorption and adsorption for Norway spruce (Picea Abies) and Scots pine (Pinus Sylvestris) at 20°C (Nilsson, 1988).

The shrinkage of wood perpendicular to the grain is higher than shrinkage of wood parallel to the grain (if the wood dries below the fibre saturation point which is about 30% moisture content). Therefore, timber should be stored at the moisture content closer to the equilibrium to be used for in service. Prevention of timber shrinkage deformation in service creates tension perpendicular to the grain and finally leads to potential failure. As the timber has different shrinkage in radial and tangential directions, split can occur if a large cross section of timber dries too fast.

Wood is a hygroscopic material, which means that if the humidity in the atmosphere is kept constant for a sufficiently long time, wood attains a moisture content that is in equilibrium with the surrounding water vapour conditions. This means that the relative humidity is the same in the air and in the wood. When the equilibrium moisture content is reached no transport of water in or out of the wood occurs.

The normal way to define the moisture content in wood is:

$$\omega = 100 . (\omega_m - \omega_o) / \omega_o$$

Where ω_m is the weight of the wet timber and ω_o is the weight of the oven-dry timber, ω is the moisture content expressed in percent.

The moisture content is not only dependent on the relative humidity of the surrounding air, it is also dependent on whether the wood is gaining or loosing water at the time. Desorption always leads to higher moisture content than adsorption, in the figure above. This phenomenon is called hysteresis.

In freshly cut timber, so called "green" wood, water is present both in the cell cavities as free water and in the cell wall as bonded water. When the water goes out from the cell, the free water in the cavities evaporates first. At moisture content of 27-30% all the free water is removed and only the water in the cell walls remains. This moisture content level is called the fibre saturation point (FSP). Above the fibre saturation point most of the mechanical properties are constant; below this point the moisture content has a significant influence on the mechanical properties.

As wood is an anisotropy material, it could easily change its shape when it dries improperly. Anisotropy transverse swelling of timber may cause distortion on a cross section upon drying. Tangential shrinkage of wood material is twice the radial shrinkage. This anisotropy shrinkage develops internal stresses on the cross section, which may be released in development of radial crack. Therefore, shape stability of the timber is a very important factor for the building sector. Timber for construction purpose should have desired dimensions with a minimum of deviation and retain its shape in the wide range of humidity condition (30-80% relative humidity i.e. moisture content in between 8 and 18%). During drying of timber, four different modes of distortion occur. The modes are twist, spring, cup and bow in which this report focuses on twist.

Twist

spring

Cup

bow
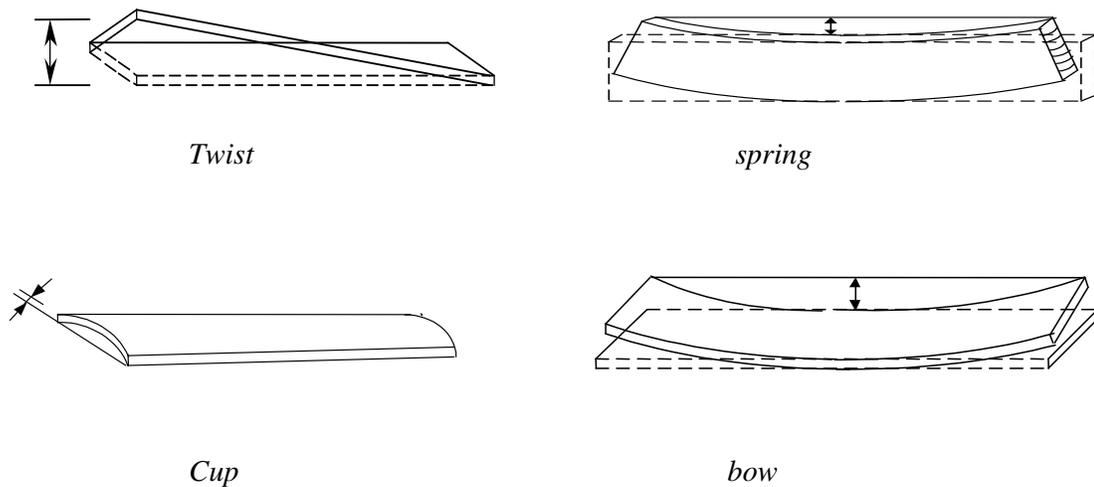
Figure2.4   Definition of distortion modes (Bäckström 2004).
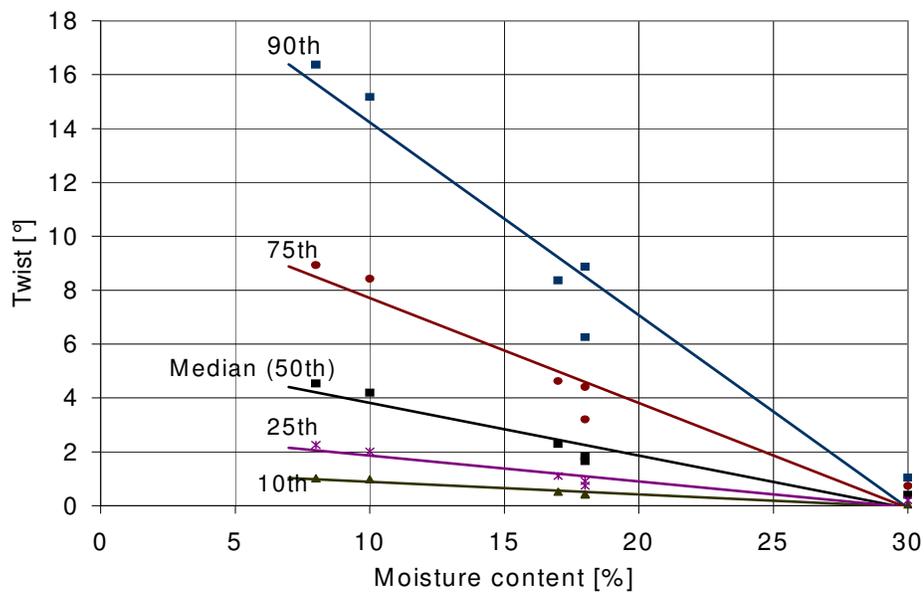
Figure 2.5   Twist in absolute values, verses moisture content (MC) for different percentages (Bäckström 2004).

2.2.2   Spiral grain and conical angle.

A phenomenon at the tree stem level that can strongly influence the material orientation is the so-called spiral grain effect but the conical orientation of the fibres is also of importance. Spiral grain means the wood fibres being oriented in a spiral manner rather than parallel to the pith axis. The fibres of the wood around the pith axis are oriented in a spiral formed manner and the angle between the pith axis and the fibre is referred as the spiral grain angle θ. The spiral grain angle θ is larger near

the pith and decreases with the distance from the pith. The angle varies from 5.5 degrees down to – 2.0 degrees.

There is another important parameter that has effect on the material orientation called conical angle. The conical effect is due to the fact that a tree stem is usually not of a straight cylindrical shape but is slightly conical. The conical angle ϕ is the deviation of wood conical shape. The conical angle may vary with the distance from the pith. Both the spiral grains angle and the conical angle are explained in the following Figure 2.7.
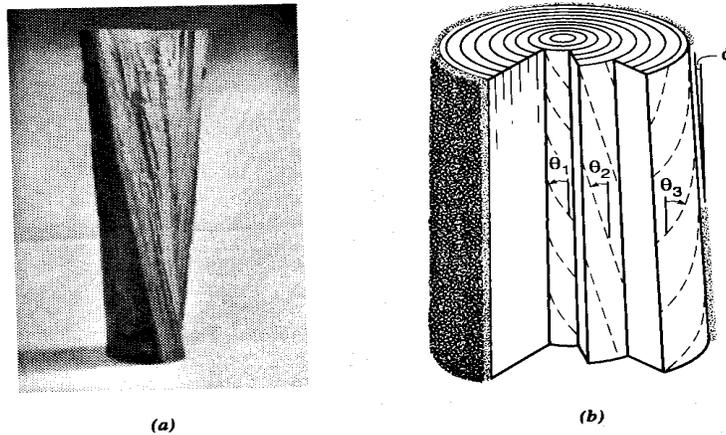
Figure 2.6   Illustration of the log structure (Ormarsson 1999).

> *a) An example of surface splitting on a log with spiral grain.*

> *b) The material orientation of the wood, the spirals grain angle θ and the conical angle ϕ.*
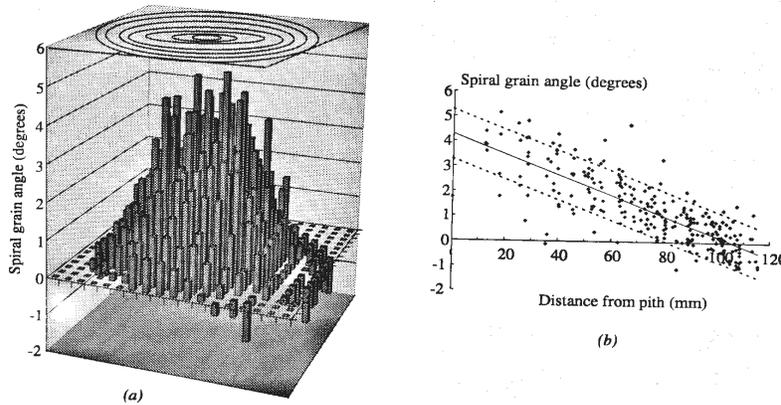
Figure 2.7   Experimentally obtained results in spiral grain of Norway spruce (Ormarsson 1999).

> *a) Variation over a cross section of log.*

> *b) Variation from pith to bark.*

2.3 Walls

2.3.1 General view

A wall can be distinguished in terms of its position, (an interior wall or an external wall) or in terms of the load it supports, i.e., a load-bearing wall or a non-bearing wall (partition). An interior wall is a building component and its most important function is that it should be to divide an area to smaller sections. Furthermore, in many cases structural engineers use a wall as a stabilising element when an entire house is subjected to wind or earthquake loads. When a wall supports a vertical load from above, it is often called a load-bearing wall. Usually, the external walls in detached or semi-detached houses are load-bearing walls, while the interior walls are partitions. Even if they are not formally load-bearing walls, should still resist the horizontal loads imposed by people, furniture, and so on.

Other functional requirements that can be set for walls are: climatic protection (thermal insulation or protection from wind, rain, moisture and so on), acoustic insulation and fire protection. These requirements vary depending on the country, region, and type of building, position in the building and use of rooms.

The main aim of this master thesis is to study the connections and distortion of timber component that is used for partition walls. In this regard it is necessary to discuss more about partition walls and its behaviour under different climatic conditions.

2.3.2 Partition walls

The partition wall is not a load bearing wall, but a physical component that separate two rooms. Partition walls are made of stud, nogging, bottom plate, top plate, cladding (mostly made of gypsum wallboard). A partition wall, as can be seen in Figure 2.8, is made of different connections like connection between stud and bottom and top plates, connection between stud and cladding and connection between nogging, stud and cladding.

These followings are the most important factors to be fulfilled by partition walls:

1. Separating the two rooms

2. To fix and mount easily

3. Having smooth surface

4. The timber component of the walls should have enough shape stability during the service

5. Acoustic requirement

6. Must have enough stiffness
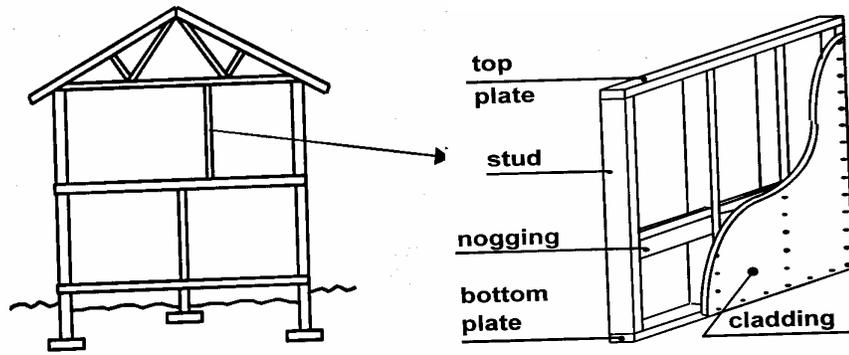
| a) Cross section of a timber building. | b) Structure of partition wall. |

Figure 2.8   A house with a partition wall (Bäckström. 2004).

2.3.3 Composition of partition walls

The stud, nogging, bottom plate and top plate are fastened mostly either by nail or screw. The gypsum wallboard is normally fastened to the stud by screws. Nowadays the common width of wallboard is 900 mm, but in the past the standard width of wallboards was 1200 mm. In the past distance between studs was either 600 mm or 1200 mm for the construction of the partition walls. To erect a wall with studs, there are different methods. The first alternative way is to choose spacing between studs 900 mm and use additional noggins. The second alternative is to use 450 mm spacing between studs without additional noggins. The third alternative is to choose 600 mm spacing between studs together with a T-shaped strip and two noggins in the wallboard joint without any support, the fourth one is to choose 600 mm spacing between studs and put plywood or OBS cladding of 600 mm or 1200 mm width in between the studs and the 900 mm gypsum cladding. The last alternative is rather expensive for a partition wall, but it will be used for load bearing walls such as shear walls. The important thing is to have stable, straight and stiff studs, which must keep their shape despite of the surrounding climatic variations. The other important factors for partition walls are the erection methods, properties of gypsum wallboard and system of fasteners.
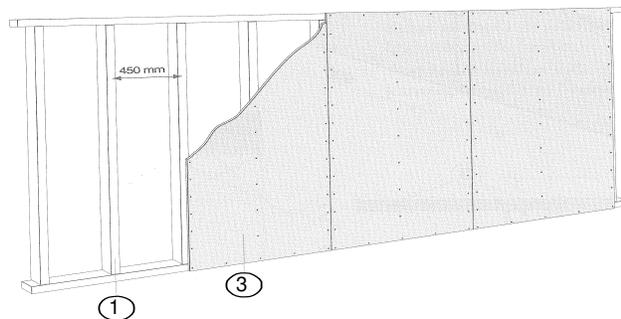
Figure 2.9   Erecting a partition wall using 900 mm gypsum wallboard cladding with a stud spacing of 450mm (Anon 2003).
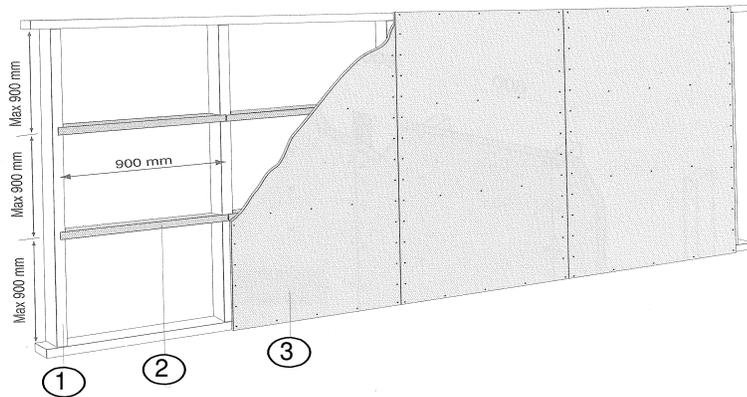
Figure 2.10 Erecting a partition wall using 900 mm gypsum wallboard cladding with a stud spacing of 900 mm (Anon 2003).
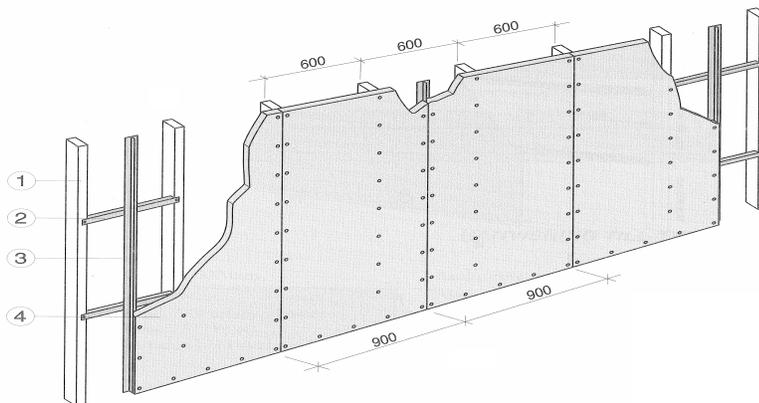
Figure 2.11 Erecting a partition wall using 900 mm gypsum wallboard cladding using 600 mm stud spacing and Additional horizontal noggins and vertical T-shaped light gauge noggins at the edge of the cladding without support of a stud (Anon 2003).

2.3.4 Shear walls

Shear walls are usually subjected to vertical loads as well as horizontal (wind loads), and in the USA they are often used to cope with the dynamic loading generated by earthquakes. The vertical loading, in most of the cases, consists of a combination of dead and imposed loads coming from the overlaying floors or roof.

A typical shear wall consists of three main components: the framing, the sheathing and the sheathing to framing connectors. The framing consists of vertical studs spaced at regular intervals of usually 600 mm. The stud standard height is 2400 mm and its cross section depends on the vertical applied load. In Sweden the common cross

section of a stud is 45 x 95 mm where as it is 44 x 97 mm in UK and in USA it is 38 x 89 mm. The sheathing material is usually made of plywood or oriented strand-board (OSB), but other materials can be used, i.e. wafer-board, fibreboard etc.

There are other types of shear walls in which gypsum sheathing is used instead of plywood for the interior wall finish. Since the gypsum sheathing does not contribute sensitively to the racking resistance of the stud panel, a diagonal steel bracing is sometimes provided inside the racking panel itself. This type of wall is called *composite shear wall*. Following Figure 2.12 shows an example of a shear wall.
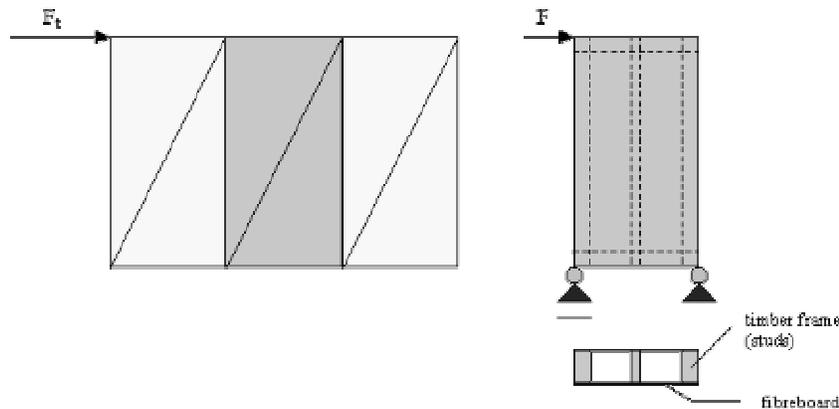
*Figure 2.12   Static designs of shear walls (*Premrov & Dobrila 2002).

2.4 Connections and joints

2.4.1 General

Most timber connections with mechanical fasteners (bolts, nails, screws and so on) are in design calculations assumed pinned. In general the problem with timber is that it is not well suited to transfer large concentrated forces induced by the fasteners (Rodd 1996). An additional problem is that in order to avoid initial slip, fasteners clearance (gaps) should be avoided, but if there is no clearance there is the risk of splitting of the timber during assembly or due to moisture-induced movements of the timber. The load carrying capacity of the timber member decreases when holes are drilled. The connections between studs and gypsum cladding in partition walls are both mechanical, such as screws, nails and staples or adhesives such as glue.

Addition of structural adhesives provides friction within the connections, which is very advantageous for transferring moment, as discussed by (Rodd 1996). Mechanical connections are not the only solution, but at the moment, structural on-site gluing is more or less out of the question, which is adhesive. The only alternative connection type is the traditional log-frame "mortise-and-tenon" connection (Sandberg et al 1996). There are many mechanical connection types, including some pre-engineered timber connectors (e.g. column bases, hold-downs, beam seats and purlin hangers), most of which constitute pinned connections, see Figure 2.13 for example.
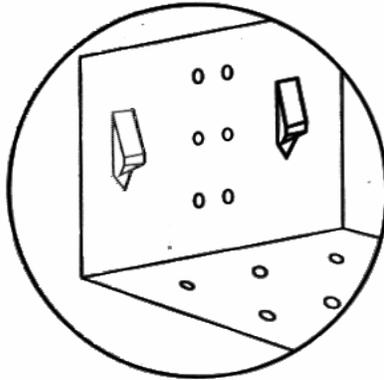
Figure 2.13   Speed-Prongs in face hanger type connector (Picture based on Simpson Strong-Tie product catalogues, 1994, 1995, 1996).

Earthquake resistance of timber frame building is in the great extend governed by connectors that tie together structural elements and entire structures to foundations. Fasteners and anchors play also an important role of energy dissipaters and controllers of dynamic properties of structural system. They might be designed and constructed as engineered devices but also the ordinary ones give their valuable contribution to behavior of structure while exposed to dynamic load. There is a constant need for knowledge and databases of behavior of different structural connections, in which joints are one of them. The inelastic response of lateral resistance of timber-frame walls and seismic response of timber-frame buildings can be obtained by cycle loading testing.

2.4.2   Requirements

Even though there is a plethora of connection types available, the need remains to develop connections in timber structures further, especially for moment-resistance, see for example (Bjorhovde and Suddarth 1993). The requirements for connections are dependent on the application of the connection in the structure and the strength of the joint as well.

There is a definite knack in the successful design of timber connections. There are several features inherent in timber to be considered by the engineer. (Faherty and Williamson 1995) sum up the more important aspects on construction design. For structurally sound connections, due consideration should be given to a number of aspects according to Faherty.

Connections and fasteners must be placed to avoid tension perpendicular to the grain in the timber. This tension can be the direct result of the load on the connection or of the moisture movements of the timber members, if the fasteners do not allow the timber to shrink and swell freely. The end and edge distances of the fasteners must be sufficient to avoid premature splitting transfer of forces should be secured without notches or eccentricities. The compression bearing areas perpendicular to the grain

must be sufficient. To keep the reduction in strength in the main members as low as possible, tapping and drilling in the elements should be avoided or kept to a minimum.

For safety reasons, the most probable failure modes in a structure should not correspond to sudden failures. If possible, failure in a timber structure should not occur in the elements since timber failures often are sudden, except for compression perpendicular to the grain. The only way of governing the failure mode not to be sudden is through the design of the joints. Ductile connections and a slightly lower yield load of the connections than the failure load of the elements makes design for a failure mode possible. Ductile connections are also preferable to avoid disproportionate collapse of the structure.

In addition to strength, stiffness and ductility, the long-term effects and creep properties of the connection are important. The sensitivity of load-duration effects for the different failure modes governs the long-term load-carrying capacity of mechanical connections; see (van de Kuilen 1995). Also, changing temperature and humidity has a significant affect on the behaviour of the joint. For example, an adhesive must be age, weather and temperature resistant.

2.4.3   Mechanical connections

The present master thesis work involves on the connection of studs and gypsum cladding in partition walls with screws. Here screw connector is designed as spring element in Abaqus to connect the stud and gypsum. The most common connector between the cladding and the studs are mechanical connectors, especially screws, c.f. Figure 2.14 below. Connections with nails or staples are also possible but are not often used. For a partition wall the main function of the connection is to keep the cladding firm to the stud providing a smooth and straight background for wallpapers or paint. The load on a connection in a partition wall is normally small compared to its capacity.
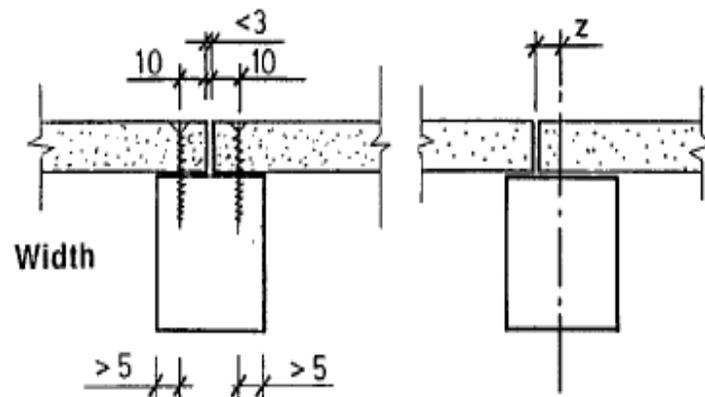
Figure 2.14   The most common connector between the cladding and the studs (Kliger, et al. 1994).

The type, number and spacing of the connectors are recommended in handbooks provided by the manufactures, i.e. "Gyproc handbook" (Anon 1999; Anon 2003). The spacing of the screw is provided depending on the buckling load in the weak and strong directions (Degerman et al. 1975). All the projects where connections between studs and cladding have been tested had a main focus on the behaviour on the light timber frame structure and it's sheathing when it is exposed to external forces, to large extent horizontal forces caused by wind.

2.4.4 Adhesive connectors

For some applications adhesive joints are necessary or provide a much easier mounting of the cladding, for example mounting cladding to stone materials or concrete. Using adhesive for partition walls is sometimes used and is a fast method mounting the cladding. However, equipment for both adhesive and screws are needed since the cladding needs to be "temporarily" fastened by screws awaiting the adhesive to cure.

2.5 Components of partition walls

2.5.1 Wall studs

The requirements for a wall stud can be traced back to the requirements for a wall, as specified in the practice code, for example. This leads to specific requirements for the timber studs. For example, a limit on the curvature of the wall leads to maximum level of acceptable crook for the studs. The studs must also have properties that enable the wall to be erected effectively and rationally. The maximum value for the curvatures and inclination of a wall is ± 5 mm for a length of 250 mm and ± 12 mm for a length of 2000 mm, for example. The maximum slope for a wall is ± 4 mm measured over the entire length, up to 2700 mm.

The traditional method using timber studs with dimensions 45 x 70 mm or 45 x 90 mm to fasten to the top and bottom plates and to the noggings is by screw nailing. This is a simple and flexible method since it only uses a limited number of components.

2.5.2 Gypsum wallboard

There are two types of gypsum wallboards. One is made of three different layers, a core of gypsum and coating of paper. Another is the homogeneous board made of a mixture of gypsum and very small pieces of paper brought together under heat and pressure see Figure 2.15.The first type of gypsum wallboard composed of a core of gypsum and coating of paper is very common in Scandinavia. The core consists to more than 90% of gypsum; calcium sulphate dehydrates several different adhesive less than 1%. The advantage of gypsum wallboards compared to wood-based wallboards (Anon 1999) is:

- The gypsum wallboard has high dimensional stability in a wide range of moisture content from 10%MC to 80% MC.

- Good fire resistance capacity.

- It is easy to cut into suitable pieces.
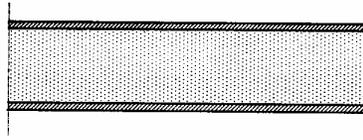
Figure 2.15   Principal sketch of the gypsum board with a core of gypsum and coating paper (Bäckström 2004).

2.5.3 Screw

Wood screw is suitable for steel to timber, panel to timber and timber-to-timber joints. Such joints are mainly designed as single shear joints. Screws with a diameter greater then 5 mm should be turned into pre-drilled holes to prevent splitting of the wood. Requirements referring to design and material of the screws will be fixed in the European product standards. In the design equations of the diameter of the screws, the diameter of coach screw varies from 8 mm to 20 mm. In this study screw T29 is used. The dimension will be: L=29 mm d=3.9 mm. All the screws look more or less same in size, shape and dimensions, so (b) in the Figure 2.16 is more appropriate to choose.
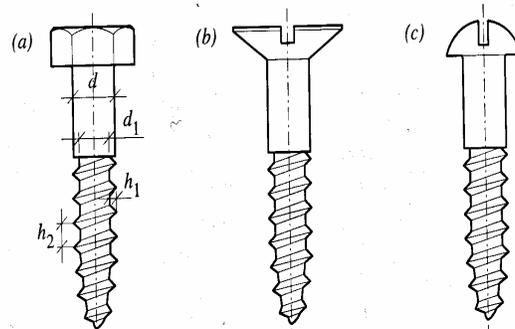
Figure 2.16   Different types of screws (Ehlbeck, and Ehrhardt 1995)

3 FEM-Theory

3.1 General description

The finite element method (FEM) is applicable for arbitrary differential equations, in order to obtain an approximate solution to the problem. FE formulations can be used for different problems in different fields such as heat conduction, torsion of elastic shafts, diffusion, ground water flow, and elastic behaviour of one, two and three-dimensional bodies, including beam and plate analysis. Here in this work we use FE analysis for calculating the angle of distortion in timber studs.

The whole physical phenomena that encountered in engineering mechanics can be modelled by differential equations. Some of these equations are too complicated to be solved by classical analytical methods. To solve these complicated differential equations in an approximate way, the finite element method (FEM) is the most applicable tool for the purpose. Description of physical problems by differential equations is assumed to hold over a certain region. The region might be one, two or three-dimensional. The characteristic feature of the finite element method is to divide the certain selected region into smaller parts, so-called finite element, in order to solve the problem in an approximate manner.

3.2 Weak formulation of equilibrium equation

The weak formulation of equilibrium for a linear elastic three-dimensional problem is (Ottosen N.S and Petersson H 1992):

$$\tilde{\nabla}^T \sigma + b = 0 \tag{3.1}$$

Where

$$\tilde{\nabla} = \begin{bmatrix} \dfrac{\partial}{\partial x} & 0 & 0 & \dfrac{\partial}{\partial y} & 0 & \dfrac{\partial}{\partial z} \\ 0 & \dfrac{\partial}{\partial y} & 0 & \dfrac{\partial}{\partial x} & \dfrac{\partial}{\partial z} & 0 \\ 0 & 0 & \dfrac{\partial}{\partial z} & 0 & \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial x} \end{bmatrix} \tag{3.2}$$

Here ∂ is the stress vector and b is the body force vector.

$$\sigma = \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{xz} \\ \sigma_{yz} \end{bmatrix} \tag{3.3}$$

$$b = \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} \tag{3.4}$$

By multiplication of Eq (3.1) to arbitrary weight function v and integration over the whole volume obtains this new equation equilibrium

$$\int_V v^T \tilde{\nabla}^T \sigma dV + \int_V v^T b dV = 0 \tag{3.5}$$

The arbitrary weight function v can be written:

$$v = \begin{bmatrix} v_x(x, y, z) \\ v_y(x, y, z) \\ v_z(x, y, z) \end{bmatrix} \tag{3.6}$$

Following equation will be obtained, by using the Green-Gauss theorem and integration of Eq (3.5)

$$\int_V (\tilde{\nabla} v)^T \sigma dV = \int_S v^T t dS \int_V v^T b dV \tag{3.7}$$

Here t is the traction vector and represent the stresses on the surface. The vector can be defined as:

$$t = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \tag{3.8}$$

$$t_x = \sigma_{xx}n_x + \sigma_{xy}n_y + \sigma_{xz}n_z$$

Where
$$t_y = \sigma_{yx}n_x + \sigma_{yy}n_y + \sigma_{yz}n_z$$

$$t_z = \sigma_{zx}n_x + \sigma_{zy}n_y + \sigma_{zz}n_z$$

To obtain finite element equations, the displacement vector u should be approximated as a function of nodal displacement. By multiplying the so-called shape function N to nodal displacement a, displacement vector u will be:

$$u = N\ a \tag{3.9}$$

Here N is so-called shape function and can be written in matrix form as:

$$N = \begin{bmatrix} N_1 & 0 & 0 & N_2 & 0 & 0 & \dots & N_n & 0 & 0 \\ 0 & N_1 & 0 & 0 & N_2 & 0 & \dots & 0 & N_n & 0 \\ 0 & 0 & N_1 & 0 & 0 & N_2 & \dots & 0 & 0 & N_n \end{bmatrix} \tag{3.10}$$

$$u = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} \tag{3.11}$$

According Gelarkin method the weight vector v can be written as:

$$v = N\ c \tag{3.12}$$

Here c is an arbitrary vector. The derivation of Eq (3.12) can be written:

$$\tilde{\nabla}v = \tilde{\nabla}Nc \tag{3.13}$$

Where

$$B = \tilde{\nabla}N \tag{3.14}$$

Inserting Eq (3.24) in the week form Eq (3.17), the following will be obtained

$$c^T\left(\int_V B^T\sigma dV - \int_S N^T t dS - \int_V N^T b dV \right) = 0 \tag{3.15}$$

The above equation equilibrium can be written:

$$\int_V B^T\sigma dV = \int_S N^T t dS + \int_V N^T b dV \tag{3.16}$$

To form FE formulation, it is necessary to introduce kinematics and constructive relations to Eq (3.16)

The kinematics and constitutive relation between strain and displacement will be:

$$\varepsilon = \tilde{\nabla} u \qquad (3.17)$$

By combining Eq (3.12) and Eq (3.17), there will be:

$$\varepsilon = Ba \qquad (3.18)$$

This following will be the constitutive relation between stresses and strain

$$\sigma = D\varepsilon \qquad (3.19)$$

$$\sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{bmatrix} \qquad (3.20)$$

$$\varepsilon = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{bmatrix} \qquad (3.21)$$

The compliance matrix C for orthotropic material will be the inverse matrix of D and is defined as

$$C = \begin{bmatrix} \dfrac{1}{E_t} & -\dfrac{v_{rl}}{E_r} & -\dfrac{v_{tl}}{E_t} & 0 & 0 & 0 \\[2ex] -\dfrac{v_{lr}}{E_t} & \dfrac{1}{E_r} & -\dfrac{v_{tr}}{E_t} & 0 & 0 & 0 \\[2ex] -\dfrac{v_{lt}}{E_t} & -\dfrac{v_{rt}}{E_r} & \dfrac{1}{E_t} & 0 & 0 & 0 \\[2ex] 0 & 0 & 0 & \dfrac{1}{G_{lr}} & 0 & 0 \\[2ex] 0 & 0 & 0 & 0 & \dfrac{1}{G_{lt}} & 0 \\[2ex] 0 & 0 & 0 & 0 & 0 & \dfrac{1}{G_{rt}} \end{bmatrix}$$

(3.22)

Combination of Eq (5.8) ad Eq (5.9) becomes

$$\sigma = DBa$$

(3.23)

Inserting Eq (3.23) into Eq (3.16), gives the following equation:

$$\int_V B^T BDdVa = \int_S N^T t dS + \int_V N^T b dV$$

(3.24)

Where

$$K = \int_V B^T DBdV$$

(3.25)

$$f_b = \int_S N^T t dS$$

(3.26)

$$f_l = \int_V N^T b dV$$

(3.27)

3.3 FE formulation for deformation

The strong form of the equation is (Ottosen N.S and Petersson H 1992)

$$\tilde{\nabla}^T \sigma + f_b = 0$$

(3.28)

In the equation $\tilde{\nabla}$ is a differential operator, σ is a stress vector and f_b is a body force vector. $\tilde{\nabla}, \sigma$ And f_b as matrices can be written

$$\tilde{\nabla} = \begin{bmatrix} \dfrac{\partial}{\partial x} & 0 & 0 \\[8pt] 0 & \dfrac{\partial}{\partial y} & 0 \\[8pt] 0 & 0 & \dfrac{\partial}{\partial z} \\[8pt] \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial x} & 0 \\[8pt] \dfrac{\partial}{\partial z} & 0 & \dfrac{\partial}{\partial x} \\[8pt] 0 & \dfrac{\partial}{\partial z} & \dfrac{\partial}{\partial y} \end{bmatrix}$$

(3.29)

$$\sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{xz} \\ \tau_{yz} \end{bmatrix}$$

(3.30)

$$f_b = \begin{bmatrix} f_x^b \\ f_y^b \\ f_z^b \end{bmatrix}$$

(3.31)

If the strong form Eq. (3.51) will be multiplied by an arbitrary function vector v as a form

$$v = \begin{bmatrix} v_x(x, y, z) \\ v_y(x, y, z) \\ v_z(x, y, z) \end{bmatrix}$$

(3.32)

Then integrated over the whole volume, the result will be the following

$$\int_V v^T \tilde{\nabla}^T \sigma dV + \int_V v^T f_b dV = 0$$

(3.33)

By using Green-Gauss theorem and differentiation with regards to time, the weak form of the equation will be

$$\int\limits_V (\tilde{\nabla}^T v^T) \dot{\sigma} dV = \int\limits_V v^T \dot{t} ds + \int\limits_V v^T \dot{f}_b dV \tag{3.34}$$

The stresses on the surfaces represented with the traction vector t, as follow

$$t = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} = \begin{bmatrix} n_x & 0 & 0 & n_y & n_z & 0 \\ 0 & n_y & 0 & n_x & 0 & n_z \\ 0 & 0 & n_z & 0 & n_x & n_y \end{bmatrix} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{xz} \\ \tau_{yz} \end{bmatrix} \tag{3.35}$$

Here n_x, n_y and n_z are the outward normal vector to the surface S. By multiplying the nodal displacement vector a with the shape function matrix N, it can be obtained the global displacement vector u as

$$u = N\ a \tag{3.36}$$

Here u, N and a are defined as

$$u = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} \tag{3.37}$$

$$N = \begin{bmatrix} N_1 & 0 & 0 & N_2 & 0 & 0 & \dots & N_n & 0 & 0 \\ 0 & N_1 & 0 & 0 & N_2 & 0 & \dots & 0 & N_n & 0 \\ 0 & 0 & N_1 & 0 & 0 & N_2 & \dots & 0 & 0 & N_n \end{bmatrix} \tag{3.38}$$

$$a = \begin{bmatrix} u_{x1} & u_{y1} & u_{z1} & u_{x2} & u_{y2} & u_{z2} & \dots & u_{xn} & u_{yn} & u_{yn} \end{bmatrix}^T \tag{3.39}$$

Here n represent the number of nodes.

The displacement rate with respect to the time will be

$$\dot{u} = N\dot{a} \tag{3.40}$$

The relations between the strains and the displacement are

$$\varepsilon = \tilde{\nabla} u \tag{3.41}$$

Relations between the rate of strain and the rate of displacement with respect to the time is defined as

$$\dot{\varepsilon} = \tilde{\nabla} \dot{u} \tag{3.42}$$

Using together the Eq. (3.41) and Eq. (3.42) with respect to the basic constitutive equation:

$$\dot{\sigma} = D\dot{\varepsilon} - \dot{\sigma}_0 \tag{3.43}$$

The stresses rate will be

$$\dot{\sigma} = D\tilde{\nabla} N\dot{a} - \dot{\sigma}_0 \tag{3.44}$$

$$\int_V (\tilde{\nabla}v)^T D\tilde{\nabla} N dV \dot{a} = \int_s v^T \dot{t} ds + \int_V v^T \dot{f}_b dV + \int_V (\tilde{\nabla}v)^T \dot{\sigma}_0 dV \tag{3.45}$$

By using Galerkin's method despite of the weight function are equal to the shape function and introducing new definition B as

$$v = N \tag{3.46}$$

$$B = \tilde{\nabla} N \tag{3.47}$$

Eq. (3.40) will be defined as

$$\int_V B^T DB dV \dot{a} = \int_s N^T \dot{t} ds + \int_V N^T \dot{f}_b dV + \int_V B^T \dot{\sigma}_0 dV \tag{3.48}$$

Generally in more compact form the above relation will be as

$$K\dot{a} = \dot{P} \tag{3.49}$$

Here

$$K = \int_V B^T DB dV \tag{3.50}$$

$$\dot{P} = \int_s N^T \dot{t} ds + \int_V N^T \dot{f}_b dV + \int_V B^T \dot{\sigma}_0 dV \tag{3.51}$$

Finally Eq. (3.51) is the finite element formulation of equilibrium equation

4 FE-model of the partition wall

4.1 General description.

To solve a complicated engineering problem such as the predication of stresses in solid body and velocities in a fluid requires a mathematical model to solve by analytical or numerical methods. Numerical methods are the reasonable ones to solve the general real problem. The predominant numerical method is the finite element method (**FEM**). The basic idea of the finite element method came from advances in aircraft structural analysis. The first paper on the subject was printed in the early 1940's, but Clough found the expression of finite element methods in 1960, see Ottosen and Peterson (1992*)*. The commercial finite element method program Abaqus/cae is used in this task to solve the problem. Abaqus is an engineering simulation program that can solve problems ranging from relatively simple linear analysis to the most difficult non-linear simulations. Abaqus contains an extensive library of elements that can model any geometry.

To start with the design in Abaqus, single stud is designed with the framed properties, symmetry conditions, and boundary conditions and so on. In the second step cladding is attached to the stud. In the next step model is extended with four studs and the cladding connected on one side of the wall, which is single-sided cladding wall and finally cladding on the both sides. The screw connector is used in order to connect the stud and cladding.

The objective of this part of the report is to produce a description of the computer model for the partition wall. Through this computer simulation the behaviour of the wall panel is studied with focus on the distortion of the stud. Comparison is made between the Abaqus model outcome and the laboratory results.

The timber was modelled as an orthotropic material using linear elastic – ideal plastic material behaviour. No cracking has been modelled, even in the final stage before failure. The progress of the study towards the final model of the panel can be summarised as follows:

- Linear-elastic modelling of single stud.

- Model is designed by making it into half panel (symmetry about central axis) and linearity is implemented by means of spring connectors.

- Comparison between the results from the FEM analysis and laboratory tests.

In the first step, different elements types, such as beam elements, shell elements, plane stress elements were tested in the model. In this way, it is possible to choose the elements that give the best performance in terms of accuracy and computational memory. The mesh optimisation and refinement of the model is carried out until the distortion free finite element model is achieved.

In the second step, different problems are investigated in order to obtain a very accurate model. The most important factors affecting the panel behaviour are considered in the FEM simulation. These factors are: the isotropic property of the

sheathing material, the racking contribution of the frame to the panel, the linearity of the sheathing-to-frame connections.

In the third and final step, the whole partition wall has been modelled. The results obtained are validated by means of a comparison with laboratory tests and existing theoretical models.

4.2   Modelling of the timber frame

The frame can be seen as a structure consisting of horizontal and vertical timber elements hinged to each other. It is a common practice to consider the wall frame in a partition wall as a structure that doesn't support loads on its own. On the contrary, Tuomi and McCutcheon (1978) assume that the frame is not a mechanism. In reality, in fact, there are nails instead of hinges between horizontal and vertical studs. To simplify the model only vertical studs are used. Future work can be done with the addition of the horizontal studs to this present model.

4.3   Partition wall

A partition wall made of studs and cladding is fairly simple structure. A frame is prepared with the help of studs consisting of top and bottom plates. The gypsum cladding is most often fastened to the studs using screws, see Figure 4.1. The studs had the cross section 45 x 70 mm and the length of about 2.5 m. The gypsum cladding was of the trademark Gyproc and normal quality, GN "Gyproc normal". The size of each wallboard was 900 x 2500 x 13 mm. The screws that were used to connect the studs and cladding were standard screws, Gyproc Quick T29 of 29 mm length.

In the numerical analysis the stud is modelled as a solid material, the cladding as a shell element and the screw as a spring element. In the real practice set-up both the top and bottom plates are fixed to the ground and the top slab simultaneously, so the partition wall is symmetrical about the central horizontal axis. Taking the symmetry into consideration of the modelling, half of the original height is assumed (1.25 m of 2.5 m) as the model height. One end of the partition wall is fixed and the other end is free to rotate due to external moment.

Top plate

Studs

Cladding

Screws

Bottom plate
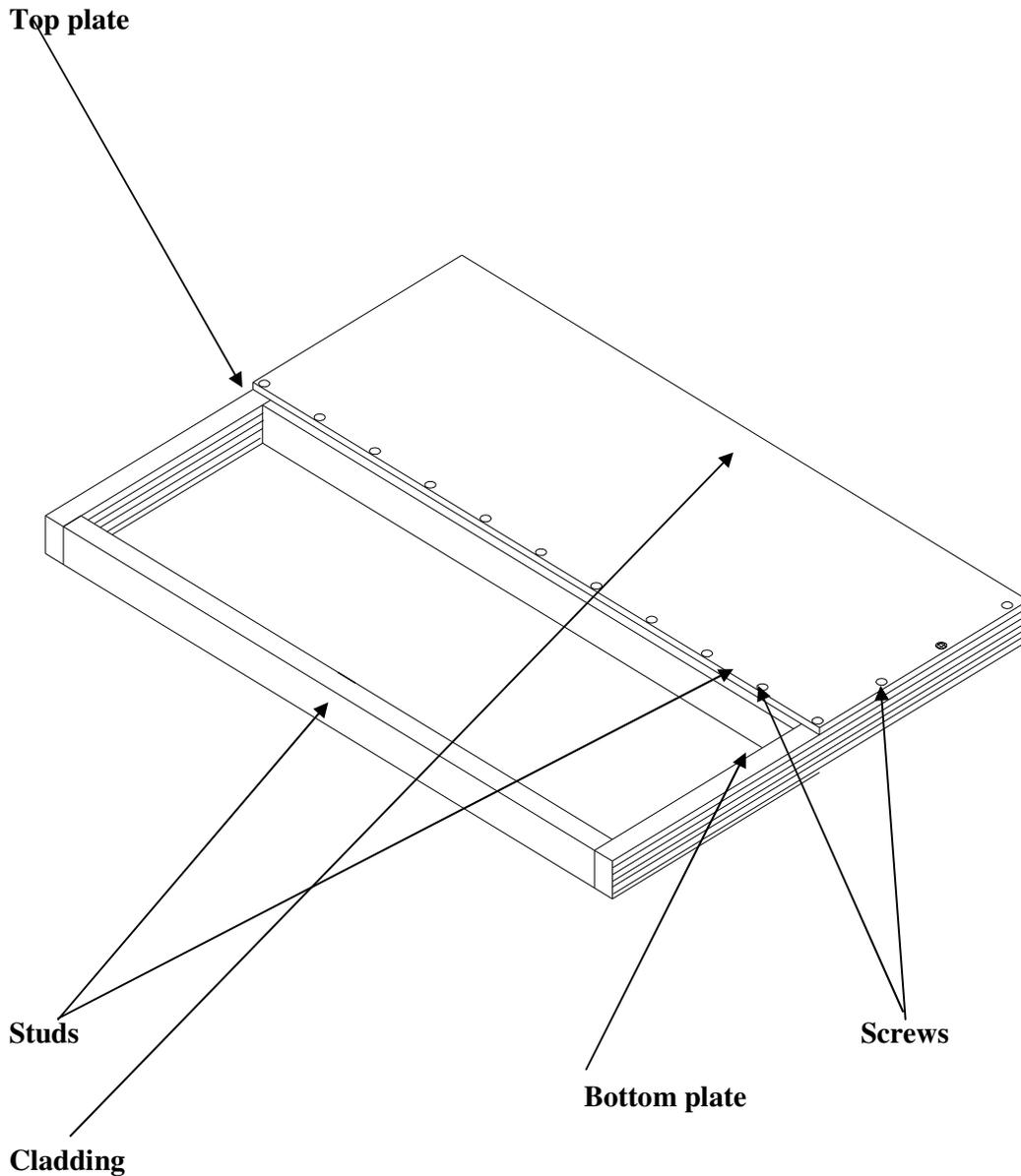
Figure 4.1   Geometry of partition wall

4.4   Stud

In the experimental set-up studs with a well-known moisture-free-distortion history were used (Johansson et al.2001; Perstorper et al. 2001; Kliger et al. 2003). The studs have proved good reversibility regarding moisture content-free-distortion, especially twist. They had a cross-section of 45 x 70 mm and a length of 2.5 m. In the finite element simulation model, the height or length of the stud was chosen as 1.25 m due to symmetrical conditions of the partition wall. In case of single-sided cladding partition wall the longitudinal stiffness properties of the four studs are assigned as

shown in the Table 4.2 based on studs in experimental setup for wall no 3, Bäckström (2004). The stiffness properties in the tangential and radial directions are calculated proportionally, according to Table 4.1. For double-sided cladding partition wall as shown in the Table 4.1 based on the wood properties, Ormarsson (1999*)*. All studs are assigned with the same material properties in the case of double-sided cladding.

Table 4.1   *Average material properties for the studs in the single-sided cladding (wall no: 2).*

All studs:

Elastic stiffness	$E_l = 9700$ MPa	$E_r = 400$ MPa	$E_t = 220$ MPa
Parameters	$G_{lr} = 400$ MPa	$G_{lt} = 250$ MPa	$G_{rt} = 25$ MPa
Average quality	$v_{lr} = 0.35$	$v_{lt} = 0.60$	$v_{rt} = 0.55$

Table 4.2   *Average material properties for the studs in the double-sided cladding (wall no: 3).*

Stud31:

Elastic stiffness	$E_l = 6727$ MPa	$E_r = 277$ MPa	$E_t = 153$ MPa
Parameters	$G_{lr} = 286$ MPa	$G_{lt} = 173$ MPa	$G_{rt} = 17$ MPa
Average quality	$v_{lr} = 0.35$	$v_{lt} = 0.60$	$v_{rt} = 0.55$

Stud32:

Elastic stiffness	$E_l = 10696$ MPa	$E_r = 455$ MPa	$E_t = 242$ MPa
Parameters	$G_{lr} = 455$ MPa	$G_{lt} = 275$ MPa	$G_{rt} = 28$ MPa
Average quality	$v_{lr} = 0.35$	$v_{lt} = 0.60$	$v_{rt} = 0.55$

Stud33:

Elastic stiffness	$E_l = 9462$ MPa	$E_r = 390$ MPa	$E_t = 214$ MPa
Parameters	$G_{lr} = 390$ MPa	$G_{lt} = 243$ MPa	$G_{rt} = 24$ MPa
Average quality	$v_{lr} = 0.35$	$v_{lt} = 0.60$	$v_{rt} = 0.55$

Stud34:

Elastic stiffness	$E_l = 9472$ MPa	$E_r = 390$ MPa	$E_t = 215$ MPa
Parameters	$G_{lr} = 390$ MPa	$G_{lt} = 244$ MPa	$G_{rt} = 25$ MPa
Average quality	$v_{lr} = 0.35$	$v_{lt} = 0.60$	$v_{rt} = 0.55$

The mass density of the stud has chosen $\rho = 450$ kg/m^3 and it is a deformable and solid extrude.

4.5 Cladding

The Gypsum Cladding was of the trademark Gyproc and normal quality, GN "Gyproc normal". The size of each cladding was 900 x 2500 x 13 mm.

Since the thickness of the gypsum board is much smaller than the width and the length, the cladding has been modelled as a shell element. As in the case of the stud, the height of the cladding is also reduced to 1.25 m due to symmetry. It is also a deformable and homogeneous material with the following property:

Density $\rho = 692$ kg/m^3, $E = 2.5$ GPa and poison ratio $v = 0.375$

4.6 Screw (connector)

The screws that were used in the tests when mounting gypsum cladding were standard screws, Gyproc Quick T29. The length of the screws was 29 mm. The distance between the screws was 200 mm on the vertical studs. However these distances had to be adjusted (shortened) at the corners.

The spring element with Cartesian type was chosen as a connector. It has 3 degree of freedom (translation). In Abaqus model also connectors are provided for every 200 mm distance and shortened at the ends. Datum points are created on the surfaces of the stud and cladding. Selecting the datum points as the ends of the connectors they are modelled as real screws.

The screws are considered to be made of steel Fe360 in real connection. In axial direction, shear capacity is $F_x = F_y = 807 \, N$ and tensile capacity is $F_z = 2061 \, N$.

The calculation of F_x, F_y and F_z are done as following:

Assumption:

The diameter of screw d =2.7mm

The area of screw section is calculated

$$A= \frac{\pi.d^2}{4} \tag{4.1}$$

$$F_x=F_y=0.6.\frac{\pi.d^2}{4}.f_y \tag{4.2}$$

$$F_z= \frac{\pi.d^2}{4}.f_{uk} \tag{4.3}$$

4.7 Rigid plate

The stud in the Abaqus model, which is designed as solid elements, doesn't support the moment forces and it is hard to observe the rotation in the particular node or element. So in order to find out the twist angle of the stud in the partition wall, a rigid plate with a reference point is created in part section and then tied to the end of each stud in the assembly section, see Figure 4.2. The size of the rigid plate is similar to the size of stud section 45 x 70 mm. Two datum points are created on the opposite vertical edges of the rigid plate, in order to apply the couple forces as the rotational moment.
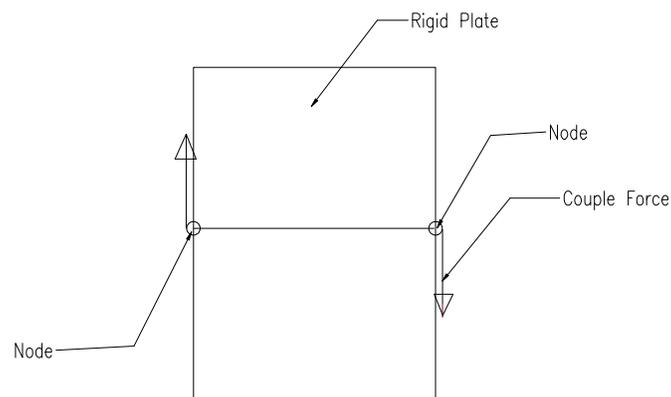
Figure 4.2   Geometry of rigid plate.

4.8   Assembly

The cladding and the stud have been modelled as different parts in the parts section. In the assembly section, instance is created in order to assemble the created parts. By means of created datum points in different parts of the model, the parts are assembled with each other by coincident constraint. The rigid plate and the studs are assembled together by means of face-to-face and coincident constraint. Surface-to-surface connections with tangential behaviour are chosen between these surfaces, in order to interact them together. In order to connect the cladding and the stud by a spring connector, datum points are created both on the stud and the cladding and a reference point is created on the surface of the cladding. By selecting the datum and reference points as the end points of the spring connector cladding is connected to the stud.

4.9   Boundary conditions and evaluation points

The partition wall in the experimental test conditions is symmetrical about the horizontal central axis which is the key feature taken into consideration in applying the boundary conditions (Bäckström 2004).

In the finite element analysis, the studs in the partition wall, both in the single-sided cladding and double-sided cladding are fixed at one end. As the element type chosen for the studs has only translational degree of freedom in the x, y, and z directions, they are locked in all directions at one end and the opposite end had a twisting moment, see Figure 4.3. A couple forces were used to apply twisting moment at the other end. The numerical analysis consistently showed more impact on the corners of the wide faces when compared to the centre. The twisted end of the numerical model better reflects the real test conditions, since the restraints in the longitudinal direction of the fixed end might slightly influence the state of stress.

Gypsum clading

Studs

1250

45   832.5   45   855   45   832.5   45

2700

BOUNDRY CONDITION (BC)

45   832.5   45   855   45   832.5   45

A —— A
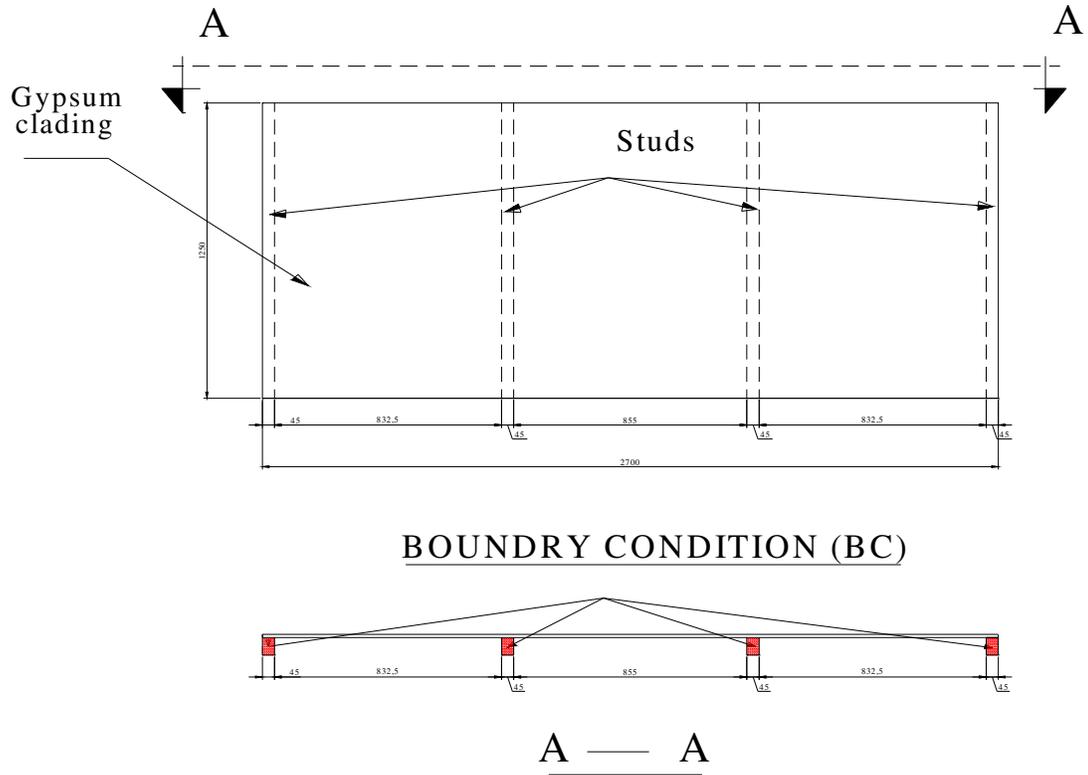
Figure 4.3   Showing the boundary condition at the end of studs.

4.10   Load

The partition wall is non-load bearing, except the internal load that is caused by moisture variation and it's self-weight. In order to test the preliminary model, a moment is applied on the free edge of the stud to confirm whether the model is working or not. In this finite element analysis, the value of the experimental twisting moment is applied at the free end of the stud, in order to find the twist angle of the stud. Couple concentrated force is used instead of twisting moment, because the finite element analysis software cannot support moment force for this type of element that is chosen. For each stud, force that will cause the same twist as in the case of experimental work is determined and is applied in the case of single-sided cladding and double-sided cladding of partition wall. The couple concentrated force applied at the free end of the stud is shown in Figure 4.2 and for the numerical values, see Table 5.3 and Table 5.4.

4.11 The element mesh

In the Abaqus input files the cladding is considered as a shell element and quadrilateral mesh elements with structural meshing technique are assigned (S4R element type).

The studs are considered as 3-dimensional deformable element, the same meshing technique is used for the studs as described above. In order to make appropriate surfaces between claddings and studs with the same dimension of studs' surfaces, the claddings are partitioned. The partition allows defining the master and slave surfaces for the assembly model, see Figure 4.5.

For this analysis, structured meshing is used for every part instance. Structured meshing gives control over mesh because it applies pre-established mesh pattern to the particular model topologies.

Making datum point during modelling in order to create connector is unavoidable, but this datum point sometime creates problem, when meshing the model. Vertex and datum point in the model deviate the mesh because seeds during seeding of the model lie on the vertex and point.

In this mode, studs are three-dimensional element type. Therefore three-dimensional mesh elements are required. The structural meshing type with a total number of 300 hexahedral elements and C3D8R element type was adopted, see Figure 4.4. The letter R at the end of element type is the abbreviation of integration reduction, during the integration and processing of the model by the software. Selecting reduction point integration can save the time and the same time can achieve satisfactory results.
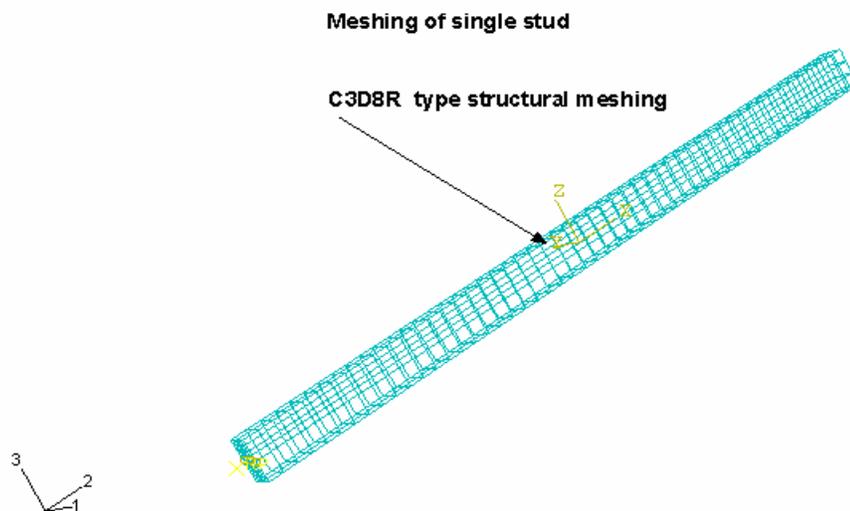
Figure 4.4   Mesh model of single stud.
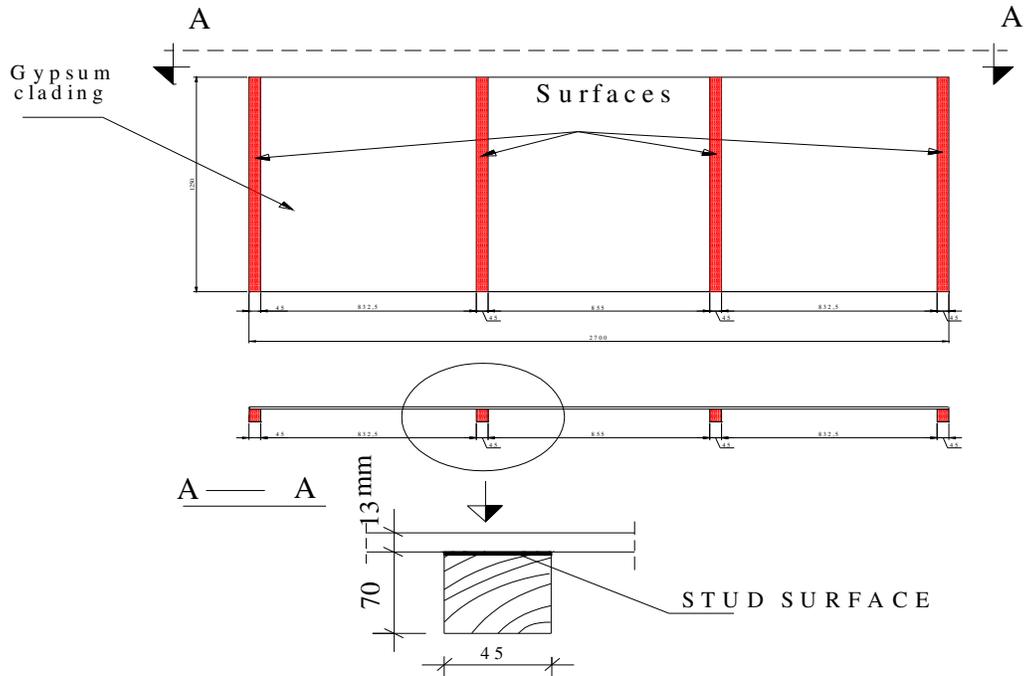
Figure 4.5   Showing the geometry of master and slave surfaces.

For single-sided cladding of the partition wall in this model, the structured meshing technique is used for both the cladding and the stud.

Since the claddings and the studs are connected with screws, many numbers of datum points are created both on the surfaces of the cladding and stud in order to connect them by spring type connector. In Abaqus two isolated points without partitioning the region between the points on both surfaces cannot be connected. This partition created on the surfaces of claddings and studs create smaller region on both surfaces. These points and smaller regions on the surfaces in turn create mesh distortion. In order to solve distortion problem, parallel vertexes are created to the points on the edges of the surfaces by edge partition.

Structured meshing technique is used for every part instance of single-sided cladding of partition wall. The total numbers of quadrilateral elements for the claddings are 2961 elements and the type element is S4R.

The total numbers of hexahedral elements in the edge of stud are 306 and 612 in the middle of the stud. This pattern was observed in each and every stud of the partition wall. As the middle studs have more datum points than the edge studs because of the more connectors, the meshing of the middle studs should be denser to avoid the distortion of the mesh. The density of the mesh will increase the number of elements in the middle stud.

Meshing of single side cladding

S4R type structural meshing
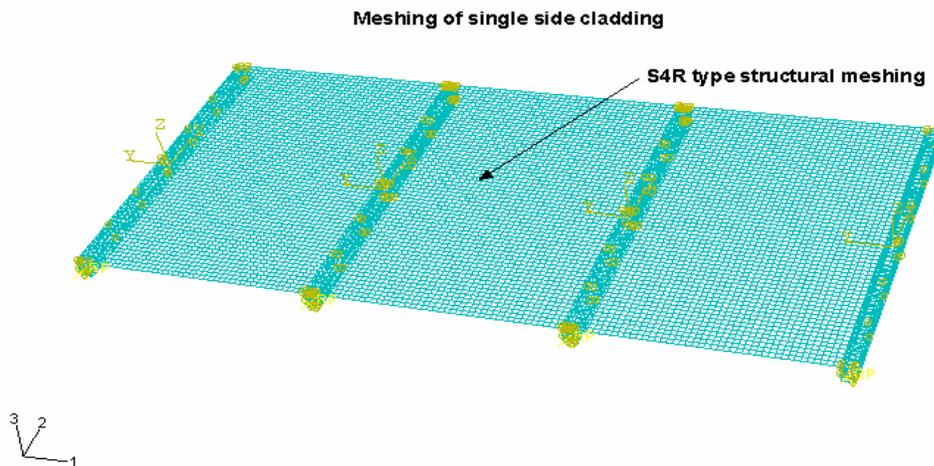
Figure 4.6   Mesh model of single-sided cladding.

For meshing the double-sided cladding of partition wall, the same technique as in the case of single-sided cladding is used. The total numbers of quadrilateral elements are 5922 for both upper and lower cladding and the type of element is S4R. The total numbers of hexahedral elements for every edge stud are 306 and for every middle stud is 316 elements with element type are C3D8R, see Figure 4.6.

Meshing of double side cladding

S4R type structural meshing
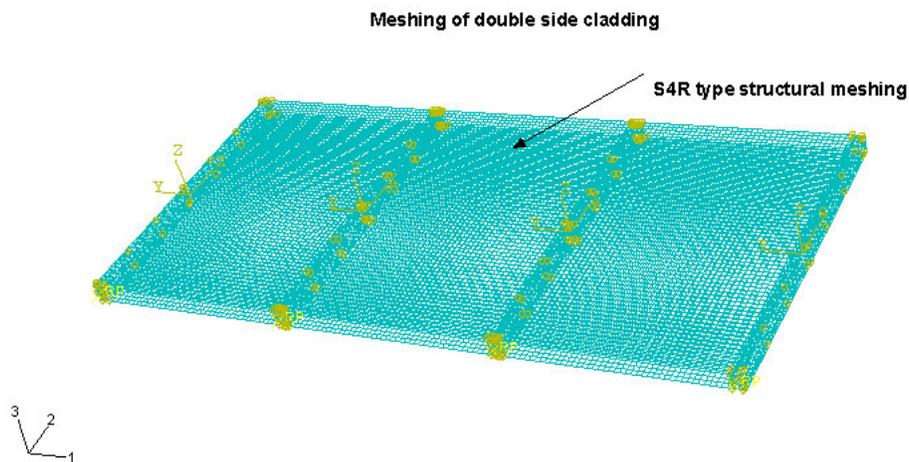
Figure 4.7   Mesh model of double-sided cladding.

5   Results

5.1   Verification of the simulation model

To check the accuracy of simulation model and to find out if it is possible to get reasonable values, the comparison is made with the test results of deformation analysis on the four single studs in single-sided cladding and double-sided cladding partition walls tested by Bäckström (2004) in his ongoing PhD work. The verification is carried out for wall no 2 and no 3 of the tests performed by Bäckström (2004). The twist angle and the twist moment were evaluated for a single stud and studs in single-side cladding and double-sided cladding.

To measure the twist angle on the studs of double-sided cladding partition wall, free and restrained twist corresponds to a difference in moisture content of about 10%. The studs had equilibrium moisture content about 18% and the room temperature kept 22°C and 35%RH. For more information about twist angle on both single stud and studs of single-sided and double-sided cladding, see Tables 3.7a, 3.7b, 3.13 and Table 3.19, in the experimental study by Bäckström (2004).

As half of the wall is modelled, therefore half the value of the twist angle, which is obtained in experimental study, is compared with the value obtained by the simulation. The experimental twist angles for both free and restrained studs in wall no 2 and wall no 3 are shown in Table 5.1 and Table 5.2

Table 5.1   Free twist and change in the restrained twist (ΔTW_{restr}) [^{o}] for the studs in wall no 3. Data measured by Bäckström (2004).

Test no	W31	W32	W33	W34
ΔTW_{rest} in wall (7-6) [^{o}]	3.1	2.9	2.3	1.2
ΔTW_{free} (7-6) [^{o}]	3.7	3.3	2.7	2.0

Table 5.2   Free twist and change in the restrained twist (ΔTW_{restr}) [^{o}] for the studs in wall no 2. Data measured by Bäckström (2004).

Test no	W21	W22	W23	W24
ΔTW_{rest} in wall (7-6) [^{o}]	0.9	1.5	1.6	1.7
ΔTW_{free} (7-6) [^{o}]	4.1	5.9	5.7	6.6

In order to check the accuracy of simulation, the tensile moment, which is obtained from the test results, is used for single stud and studs in single and double cladding of partition walls and twist angle is obtained directly from the reference point of rigid plate which is tied to the end of each stud and then compared to the test results. The element type of the studs chosen in the finite element analysis doesn't support the direct moment force to apply, so couple concentrated forces (equivalent to the moment) is used. It is also possible to calculate the twist angle by using the following Eq. (5.1).

$$\phi = \arctan\left(\frac{\delta_1 - \delta_2}{b}\right) \tag{5.1}$$

Where δ_1 and δ_2 are the transitional deflection of the two points where the couple force is applied and b is the distance between the two points.

5.1.1   Single-sided cladding

In the single-sided cladding partition wall analysis, four studs in the partition wall are assigned with same material properties as shown in Table 4.1. The results from the partition wall with gypsum cladding on one side are shown in the Table 5.3. The restrained twist is the measured twist when the studs are in the wall, i.e. the difference in twist between measurements, when the studs are free and in the partition wall are shown in Table 5.3 and illustrated in Figure 5.1.We can observe a certain difference in the twist angle between the numerical analysis and the experimental studies in the restrained studs but there is not much difference in the free studs. The couple force was set in such a way that numerical free twist will be almost the same as the experimental free twist. The twist of a stud in built-up wall is restrained to a great extent, about 83% in the numerical analysis against 75% in experimental tests.

Table 5.3   Numerically and experimentally obtained twist angle values for studs in Single-sided cladding.

Stud no	Experimental		Numerical		Couple force
	Free twist [°]	Rest. twist [°]	Free twist [°]	Rest. twist [°]	[N]
W31	3.7	3.1	3.8	3.8	130
W32	3.3	2.9	3.3	2.2	180
W33	2.7	2.3	2.7	1.6	130
W34	2.0	1.2	2.1	1.0	100
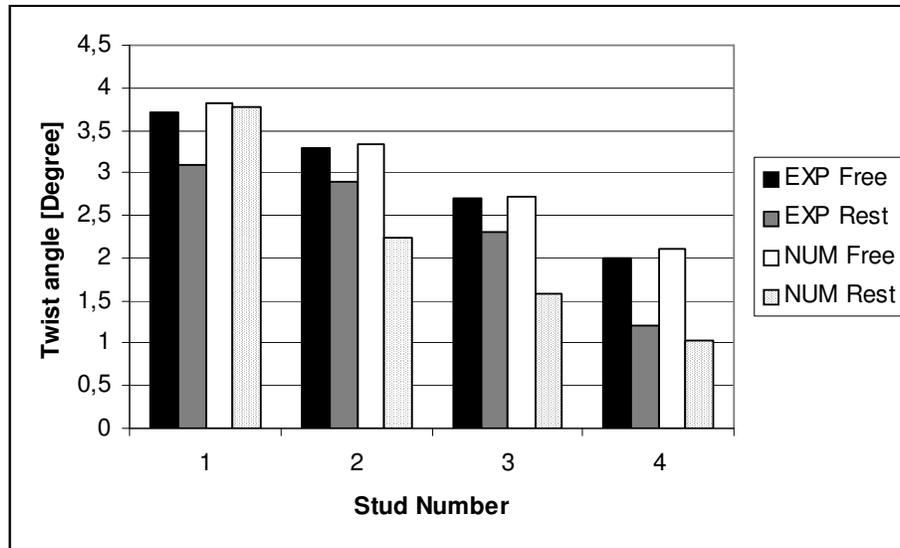
Figure 5.1   Changes in twist, free and restrained in comparison with the experimental results in case of single-sided cladding.

5.1.2   Double-sided cladding

In the double-sided cladding analysis different material properties are applied for all the four studs as shown in the Table 4.2. The results from the partition wall with gypsum cladding on both sides are shown in Table 5.4 and illustrated in Figure 5.2. Here in the double-sided cladding also we can observe that the results of restrained twist angle there is considerable difference in between the numerical and experimental test values. In the double-sided cladding, the twist of a stud in built-up wall is restrained to a great extent, about 78% in the numerical analysis.

Table 5.4   Numerically and experimentally obtained twist angle values for studs in double-sided cladding.

Stud no	Experimental		Numerical		Couple Force
	Free twist [°]	Rest. twist [°]	Free twist [°]	Rest. twist [°]	[N]
W21	4.1	0.9	4.1	1.3	200
W22	5.9	1.5	5.9	1.9	290
W23	5.7	1.6	5.7	1.4	280
W24	6.6	1.7	6.6	1.8	320
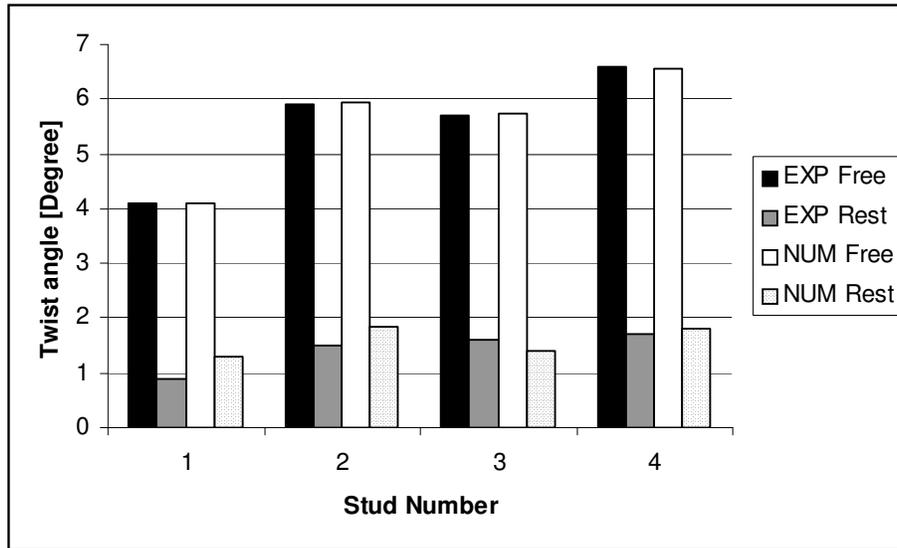
Figure 5.2   Changes in twist, free and restrained in comparison with the experimental results in case of double-sided cladding.

5.1.3   Deformation

The following Figure 5.3 shows the picture of deformation in the case of single stud. We can observe the clear twist in the case of the single stud and not much of twist when embedded in the partition wall. There is reduced twist in the case of single-sided and double-sided cladding, see Figure 5.4 and Figure 5.5.
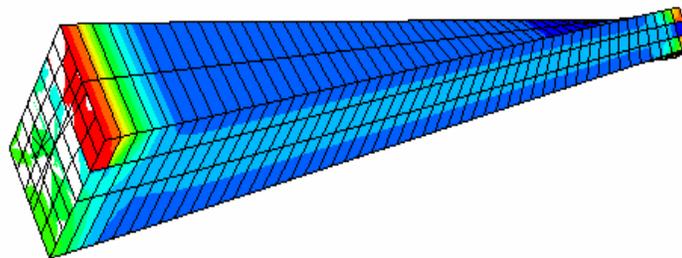
Figure 5.3   Deformation of single stud under the effect of concentrated couple force.

More stresses and deformations in the gypsum cladding was seen around the far right free end of the stud, due to the free movement and less number of connectors. The

distortion in the cladding in more, as the cladding is moving along with stud that is not the case in the other end of the partition wall.
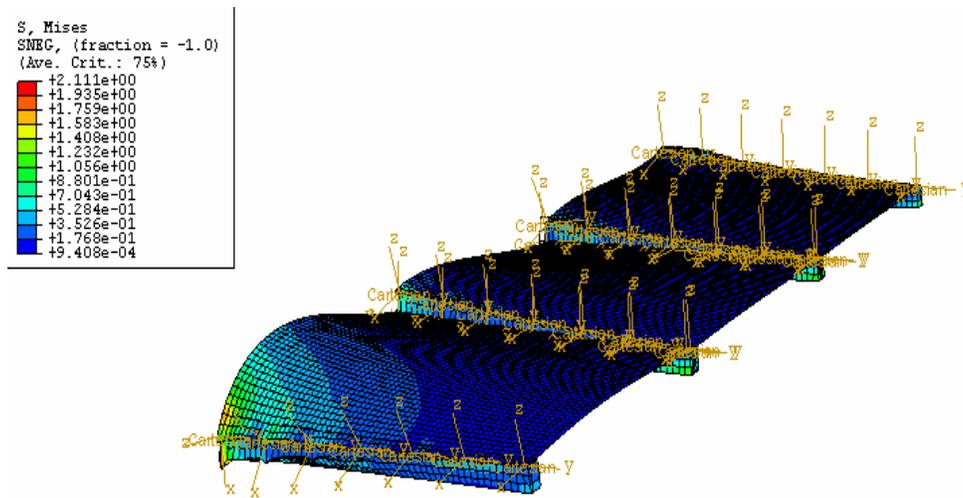
Figure 5.4 *Stresses and deformation of studs and claddings in partition wall, single-sided cladding.*
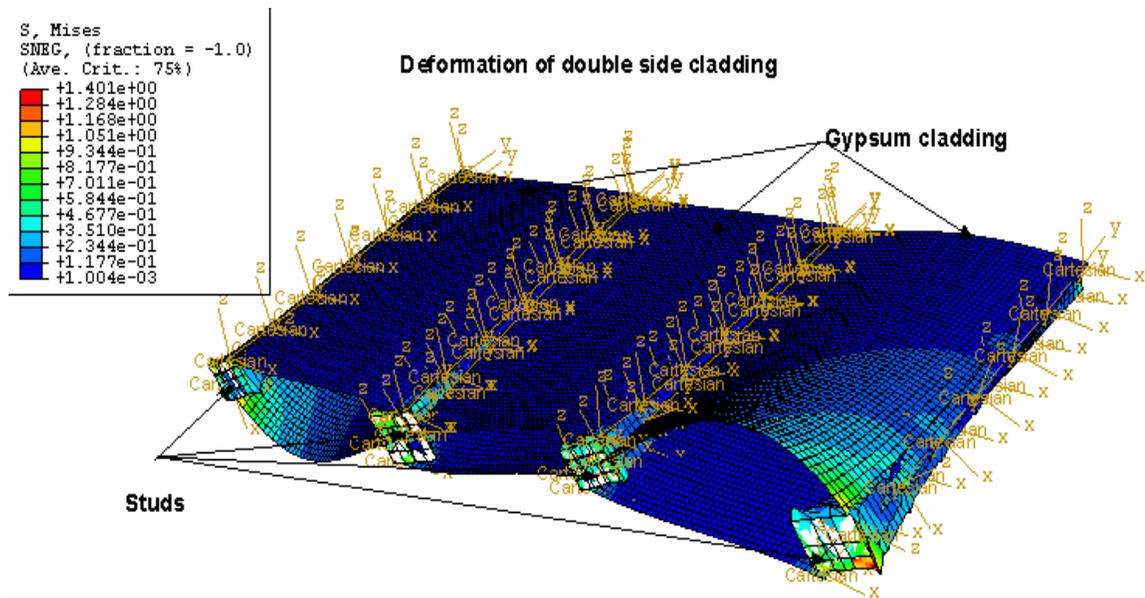
Figure 5.5 *Stresses and deformation of studs and claddings in partition wall, double-sided cladding.*

6   Conclusion

In the experimental work done by Bäckström (2004) the twist angle was calculated at the both ends and considered zero at the middle of the stud. This symmetry about horizontal axis is considered in the design of the simulation model. Half the height of the partition wall in the experiment is used for the finite element analysis.

Many things could cause the disagreement between the values obtained by simulation and tests. For example the moisture content of the wood affects the experimental results, which is not the case in simulation process.

The obtained twist angles of the studs of this simulation for the single stud and studs in the partition wall with single-sided cladding and double-sided claddings are acceptable despite of discrepancy between the values. Most importantly the twist angle for the free stud is almost same in the both the cases.

The twist angle of a free stud is much bigger than the restrained studs of a wall with gypsum cladding. The simulation shows that the twist angles of the studs in a wall with double-sided cladding are much smaller than a wall with single-sided cladding. The twist angle of the stud is varied between 6 [^{o}] for a free single stud and 0.9 [^{o}] for the stud on a wall with double-sided cladding.

The twist angles obtained from the numerical analysis and test results are almost the same in the case of free studs, because of less restriction of stud's movement in all directions. In the case of restrained studs, there is little discrepancy in the twist angles between numerical analysis and test results.

7 Future work

Since the primary aim of the simulations performed in the present study was to illustrate the twist in the studs of the partition wall due to the moment, it is very important to consider the moisture effect also. So it would be of interest, therefore, to carry out the moisture influence on the behavior of the stud.

More detailed experimental investigation of the material properties of compression wood and of how it is distributed in both the transversal and the longitudinal directions is likewise needed.

The most important and the immediate extensions of this master thesis model are to add both the top and the bottom plates. The results can be more interesting if the plates are added to this simulation model.

Further using different types of connectors and the way they are used in the connection can be more work. Different materials of cladding also can be tried.

In the development of a more adequate material model, a very large amount of experimental work will be required for adequately describing and taking account of all the material parameters.

8 References

Anon (1988a): "New Zealand Timber Grading Rules" NZS 3631:1988. SANZ 1988.

Anon (2003): Gyproc handbook 6

Andrzej, C., (1985): Analysis of shear walls.

Bengtsson, C. (1997): Creep in sawn spruce exposed to varying humidity-influence of raw material parameters. Licentiate thesis. Chalmers University of Technology, Div. of Steel and Timber Structures, Publ. S 97:1, Gothenburg, Sweden.

Bindzi and Samson, M., (1995): New formula for influence of spiral grain on bending stiffness of wooden beams. Journal of Structural Engineering, pages 541-1546.

Bjorhovde, R., Suddarth, S.K. (1993): Research needs for wood connectors and connections. Proceedings of the International Workshop on Wood Connectors. Forest Products Soceity and Forest Products Laboratory, Madison, WI, November 1992, pp. 147-148.

Blomqvist, H., (1987): Spiral-grained timber – Scaling problems – Properties of the sawn wood. Report no 194, Swedish University of Agricultural Sciences, Department of Forest Products, Uppsala.

Bodig, J. and Jayne, B.A., (1982): Mechanics of wood and wood composities. New York, USA, Van Nostrand Reinhold.

Burström, P.G., (2001): Building materials, structure, manufacture and properties. Lund, Student Literature.

Bäckström, M., (2004): Experimental study of shape stability of partition walls. Licentiate thesis. Chalmers University of Technology, Div. of Steel and Timber Structures, Publ. S 04.1, Gothenburg, Sweden.

Danborg, F., (1994): Spiral grain in plantation trees of Picea abies. Can. J. for Res., 24:1662-1671, 1994.

Degerman, T., Ramde, B., and Seling, B., (1975): Stabilizing wooden columns with nailed gypsum wallboards. Lund, Department of Building Technology, Lund Institute of Technology, 1975:61

Dolan, J. D., Madsen, B. (1992): Monotonic and cyclic nail connection tests, Canadian Journal of Civil Engineering, Vol. 19: 97-104.

Dujic, B., and Zarnic, R., (2003): University of Ljubljana, faculty of civil and Geodetic Engineering, Ljubljana, Slovenia.

Ehlbeck, J., Ehrhardt, W., (1995): Screwed joints. University Karlsruhe.

Engström, D., (1997): Connections for Timber- Framed Structures- assembly properties and structural behaviour.

Faherty, K.F., Williamson, G.T., eds. (1995): Wood Engineering and Construction Handbook. Second Edition. McGraw-Hill, New York.

Fengel, D., and Wagener, G., (1984): Wood. Walter de Gruyter.

Hibbitt, Karlsson & Sorensen, Inc (2002): Abaqus version 6.3

Hoffmeyer, P., (1995): Wood as a building material. Technical university of Denmark.

Johansson, M.; Perstorper, M.; Kliger, I.R.; Johansson, G. (1999): Distortion of Norway spruce timber- part 2. Modelling of twist. Accepted for publication in Holz ALS Roh- undWerkstoff.

Johansson, M., (2000): Moisture-related Distortion in Norway spruce Timber- Influence of Material Properties. Licentiate thesis. Chalmers University of Technology, Div. of Steel and Timber Structures, Publ. S 00:4, Gothenburg, Sweden.

Kliger, R; Johansson, G; Perstorper, M, and Engstrom, D. 1994: Formulation of Requirements for the Quality of Wood Products Used by the Construction Industry. EEC Forest Project. Div of Steel and Timber Structures, Chalmers University of Technology, Gothenburg, Sweden.

Kliger, R; Johansson, M. 1999: Swedish part of: Quantification of distortion in sawn timber measured after sawing, after drying and during different moisture loads. Final report sub-task B6.1. FAIR CT 96-1915. Report STUD.CTH.FSR.B6.1. Chalmers University of Technology, Div of Steel and Timber Structures, Gothenburg, Sweden.

van de Kuilen, J.-W.G. (1995): Influence of moisture content and load duration in joints. STEP 1 Lecture C18, Centrum Hout, Almere, the Netherlands.

Nilsson, L.-O., (1988): Moisture transport properties in wood and wooden based building materials. Chalmers University of Technology, Department of Building Materials, P-88:4:1-129.

Ormarsson S., (1999): Numerical analysis of moisture-related Distortion in Sawn Timber. Licentiate thesis. Chalmers University of Technology, Department of Structural Mechanics, publ. S 99:7, Gothenburg, Sweden.

Ottosen, N.S., and Petersson, H., (1992): Introduction to the finite element method. Prentice Hall London.

Premrov M., & Dobrila P., (2002) Reinforced prefabricated timber shear walls, Academic open Internet Journal, Vol. 8, 2002.

Rilem TC 109-TSA. (1994): Timber structures in Seismic Regions: RILEM State-of-the-Art Report, Materials and Structures, vol. 27: 157-184.

Rodd P D (1996) Locally reinforced Moment Transmitting Joints. International Wood Engineering Conference, New Orleans, USA, pp 2-169 to 2-176.

Simpson Strong-Tie Company, Inc. (1996): Samples of product catalogues: Earthquake-resistant construction connectors. Composite wood products connectors. Wood construction connectors. Connectors for timber and masonry construction.

Simpson Strong-Tie Company, Inc. (1995): Samples of product catalogues: Connectors for wood construction. High wind-resistant construction connectors.

Simpson Strong-Tie Company, Inc. (1994): Product catalogue: Connectors for the plated truss industry.

Steer, P.J., (1995): Timber in construction. Consultant Structural Engineer.

Tuomi R. L., McCutcheon W.J., (1978), Racking strength of light-frame nailed walls, Journal of the Structural Division, Vol. 104, No ST7, Proceedings of the American Society of Civil Engineers, pp. 1131-1140.

9 Appendices

9.1 Appendix A

Abaqus input file for a single stud

```
OPTIONS BEING PROCESSED

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9.2 Appendix B

Abaqus input file for a partition wall with single-sided cladding

```
PROCESSING PART, INSTANCE, AND ASSEMBLY INFORMATION

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     END PROCESSING PART, INSTANCE, AND ASSEMBLY INFORMATION

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     OPTIONS BEING PROCESSED

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*Elset, elset=ASSEMBLY__CONN-4_CNSET_

*Elset, elset=ASSEMBLY__CONN-5_CNSET_
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*Elset, elset=ASSEMBLY__CONN-6_CNSET_

*Elset, elset=ASSEMBLY__CONN-7_CNSET_

*Elset, elset=ASSEMBLY__CONN-8_CNSET_

*Elset, elset=ASSEMBLY__CONN-9_CNSET_

*Elset, elset=ASSEMBLY__PICKEDSET60

*Elset, elset=ASSEMBLY___PICKEDSURF178_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF179_S3

*Elset, elset=ASSEMBLY___PICKEDSURF180_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF181_S3

*Elset, elset=ASSEMBLY___PICKEDSURF182_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF183_S3

*Elset, elset=ASSEMBLY___PICKEDSURF184_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF185_S3

*Elset, elset=ASSEMBLY___PICKEDSURF186_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF187_S3

*Elset, elset=ASSEMBLY___PICKEDSURF188_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF189_S3

*Elset, elset=ASSEMBLY___PICKEDSURF209_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF210_S4

*Elset, elset=ASSEMBLY___PICKEDSURF211_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF212_S6

*Elset, elset=ASSEMBLY___PICKEDSURF213_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF214_S6

*Elset, elset=ASSEMBLY___PICKEDSURF215_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF216_S4

 *rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

 *rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

 *rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

 *rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

 *contactpair, interaction=INTPROP-1

 *contactpair, interaction=INTPROP-1

 *contactpair, interaction=INTPROP-1
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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF178

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF179

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF180

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF181

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF188

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF189

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF209

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF210

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF211

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF212

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF213

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF214

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF215

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF216

*rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

*rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

*rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

*rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

*contactpair, interaction=INTPROP-1
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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*tie, name=CONSTRAINT-1, adjust=YES

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*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF182

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF209

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF210

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF214

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF215

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF216

*surfaceinteraction, name=INTPROP-1

*contactpair, interaction=INTPROP-1
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*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*material, name=GYPSUM

*density

*elastic

*material, name=TIMBER

*density

*elastic, type=ENGINEERINGCONSTANTS

*surfaceinteraction, name=INTPROP-1

*friction

*surfaceinteraction, name=INTPROP-1

*connectorbehavior, name=CONNPROP-1

*connectorelasticity, component=1

*connectorelasticity, component=2

*connectorelasticity, component=3

*orientation, name=ASSEMBLY_STUD1-1_ORI-2

*orientation, name=ASSEMBLY_STUD2-1_ORI-2

*orientation, name=ASSEMBLY_STUD3-1_ORI-2

*orientation, name=ASSEMBLY_STUD4-1_ORI-2

*solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

*shellsection, elset=ASSEMBLY_CLADDING1-1__I1, material=GYPSUM
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  *shellsection, elset=ASSEMBLY_CLADDING2-1__I1, material=GYPSUM

  *shellsection, elset=ASSEMBLY_CLADDING3-1__I1, material=GYPSUM

  *rigidbody,     refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,     elset=ASSEMBLY_RIGID1-
1_RIGID1-1

  *rigidbody,     refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,     elset=ASSEMBLY_RIGID2-
1_RIGID2-1

  *rigidbody,     refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,     elset=ASSEMBLY_RIGID3-
1_RIGID3-1

  *rigidbody,     refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,     elset=ASSEMBLY_RIGID4-
1_RIGID4-1

  *rigidbody,     refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,     elset=ASSEMBLY_RIGID1-
1_RIGID1-1

  *rigidbody,     refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,     elset=ASSEMBLY_RIGID2-
1_RIGID2-1

  *rigidbody,     refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,     elset=ASSEMBLY_RIGID3-
1_RIGID3-1

  *rigidbody,     refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,     elset=ASSEMBLY_RIGID4-
1_RIGID4-1

  *contactpair, interaction=INTPROP-1

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  *contactpair, interaction=INTPROP-1

  *contactpair, interaction=INTPROP-1

  *contactpair, interaction=INTPROP-1

  *contactpair, interaction=INTPROP-1

  *tie, name=CONSTRAINT-1, adjust=YES

  *tie, name=CONSTRAINT-2, adjust=YES

  *tie, name=CONSTRAINT-3, adjust=YES

  *tie, name=CONSTRAINT-4, adjust=YES

  *boundary


  *tie, name=CONSTRAINT-1, adjust=YES

  *tie, name=CONSTRAINT-2, adjust=YES

  *tie, name=CONSTRAINT-3, adjust=YES

  *tie, name=CONSTRAINT-4, adjust=YES

  *tie, name=CONSTRAINT-1, adjust=YES

  *tie, name=CONSTRAINT-2, adjust=YES

  *tie, name=CONSTRAINT-3, adjust=YES

  *tie, name=CONSTRAINT-4, adjust=YES
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*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*contactpair, interaction=INTPROP-1




*solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

*shellsection, elset=ASSEMBLY_CLADDING1-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING2-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING3-1__I1, material=GYPSUM

*surfaceinteraction, name=INTPROP-1

*contactpair, interaction=INTPROP-1




*rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

*rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

*rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

*rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF178

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF179

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF180
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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF182

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF215

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF216

*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*connectorsection, elset=ASSEMBLY__CONN-1_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-10_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-11_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-12_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-13_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-14_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-15_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-16_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-17_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-18_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-19_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-2_CNSET_, behavior=CONNPROP-1
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*connectorsection, elset=ASSEMBLY__CONN-20_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-21_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-22_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-23_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-24_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-25_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-26_CNSET_, behavior=CONNPROP-1

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*connectorsection, elset=ASSEMBLY__CONN-28_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-29_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-3_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-30_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-31_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-32_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-33_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-34_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-35_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-36_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-37_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-38_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-39_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-4_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-40_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-41_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-42_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-5_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-6_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-7_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-8_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-9_CNSET_, behavior=CONNPROP-1

*Step, name=conection

*output, field, variable=PRESELECT

*output, history
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9.3 Appendix C

Abaqus input file for a wall with double-sided cladding

```
OPTIONS BEING PROCESSED

  ***************************

 *Heading

 *Node

 *Element, type=C3D8R

 *Elset, elset=ASSEMBLY_STUD1-1__I1

 *Node

 *Element, type=C3D8R

 *Elset, elset=ASSEMBLY_STUD2-1__I1

 *Node

 *Element, type=C3D8R

 *Elset, elset=ASSEMBLY_STUD3-1__I1

 *Node

 *Element, type=C3D8R

 *Elset, elset=ASSEMBLY_STUD4-1__I1

 *Node

 *Element, type=S4R

 *Elset, elset=ASSEMBLY_CLADDING1-1__I1

 *Node

 *Element, type=S4R

 *Elset, elset=ASSEMBLY_CLADDING2-1__I1

 *Node

 *Element, type=S4R

 *Elset, elset=ASSEMBLY_CLADDING3-1__I1

 *Node

 *Element, type=R3D4

 *Nset, nset=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_

 *Elset, elset=ASSEMBLY_RIGID1-1_RIGID1-1

 *Node
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*Element, type=R3D4

*Nset, nset=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_

*Elset, elset=ASSEMBLY_RIGID2-1_RIGID2-1

*Node

*Element, type=R3D4

*Nset, nset=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_

*Elset, elset=ASSEMBLY_RIGID3-1_RIGID3-1

*Node

*Element, type=R3D4

*Nset, nset=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_

*Elset, elset=ASSEMBLY_RIGID4-1_RIGID4-1

*Node

*Element, type=S4R

*Elset, elset=ASSEMBLY_CLADDING4-1__I1

*Node

*Element, type=S4R

*Elset, elset=ASSEMBLY_CLADDING5-1__I1

*Node

*Element, type=S4R

*Elset, elset=ASSEMBLY_CLADDING6-1__I1

*Element, type=CONN3D2

*Nset, nset=ASSEMBLY_SET-1

*Nset, nset=ASSEMBLY__PICKEDSET171

*Nset, nset=ASSEMBLY__PICKEDSET172

*Nset, nset=ASSEMBLY__PICKEDSET173

*Nset, nset=ASSEMBLY__PICKEDSET174

*Nset, nset=ASSEMBLY__PICKEDSET175

*Nset, nset=ASSEMBLY__PICKEDSET176

*Nset, nset=ASSEMBLY__PICKEDSET177

*Nset, nset=ASSEMBLY__PICKEDSET178

*Nset, nset=ASSEMBLY__PICKEDSET60

*Elset, elset=ASSEMBLY__CONN-100_CNSET_

*Elset, elset=ASSEMBLY__CONN-101_CNSET_
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*Elset, elset=ASSEMBLY__CONN-102_CNSET_

*Elset, elset=ASSEMBLY__CONN-103_CNSET_

*Elset, elset=ASSEMBLY__CONN-104_CNSET_

*Elset, elset=ASSEMBLY__CONN-105_CNSET_

*Elset, elset=ASSEMBLY__CONN-106_CNSET_

*Elset, elset=ASSEMBLY__CONN-107_CNSET_

*Elset, elset=ASSEMBLY__CONN-108_CNSET_

*Elset, elset=ASSEMBLY__CONN-109_CNSET_

*Elset, elset=ASSEMBLY__CONN-10_CNSET_

*Elset, elset=ASSEMBLY__CONN-110_CNSET_

*Elset, elset=ASSEMBLY__CONN-111_CNSET_

*Elset, elset=ASSEMBLY__CONN-11_CNSET_

*Elset, elset=ASSEMBLY__CONN-12_CNSET_

*Elset, elset=ASSEMBLY__CONN-13_CNSET_

*Elset, elset=ASSEMBLY__CONN-14_CNSET_

*Elset, elset=ASSEMBLY__CONN-15_CNSET_

*Elset, elset=ASSEMBLY__CONN-16_CNSET_

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*Elset, elset=ASSEMBLY__CONN-18_CNSET_

*Elset, elset=ASSEMBLY__CONN-19_CNSET_

*Elset, elset=ASSEMBLY__CONN-20_CNSET_

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*Elset, elset=ASSEMBLY__CONN-22_CNSET_

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*Elset, elset=ASSEMBLY__CONN-25_CNSET_

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*Elset, elset=ASSEMBLY__CONN-29_CNSET_

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*Elset, elset=ASSEMBLY__CONN-33_CNSET_

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*Elset, elset=ASSEMBLY__CONN-72_CNSET_

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*Elset, elset=ASSEMBLY__CONN-74_CNSET_

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*Elset, elset=ASSEMBLY__CONN-95_CNSET_

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*Elset, elset=ASSEMBLY__CONN-99_CNSET_

*Elset, elset=ASSEMBLY__CONN-9_CNSET_

*Elset, elset=ASSEMBLY__PICKEDSET60

*Elset, elset=ASSEMBLY___PICKEDSURF119_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF120_S2

*Elset, elset=ASSEMBLY___PICKEDSURF121_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF122_S5

*Elset, elset=ASSEMBLY___PICKEDSURF123_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF124_S5

*Elset, elset=ASSEMBLY___PICKEDSURF125_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF126_S5

*Elset, elset=ASSEMBLY___PICKEDSURF127_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF128_S5

*Elset, elset=ASSEMBLY___PICKEDSURF129_SPOS

*Elset, elset=ASSEMBLY___PICKEDSURF130_S2

*Elset, elset=ASSEMBLY___PICKEDSURF131_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF132_S4

*Elset, elset=ASSEMBLY___PICKEDSURF133_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF134_S2
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*Elset, elset=ASSEMBLY___PICKEDSURF135_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF136_S4

*Elset, elset=ASSEMBLY___PICKEDSURF137_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF138_S4

*Elset, elset=ASSEMBLY___PICKEDSURF156_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF157_S1

*Elset, elset=ASSEMBLY___PICKEDSURF158_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF159_S3

*Elset, elset=ASSEMBLY___PICKEDSURF160_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF161_S3

*Elset, elset=ASSEMBLY___PICKEDSURF162_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF163_S3

*Elset, elset=ASSEMBLY___PICKEDSURF164_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF165_S3

*Elset, elset=ASSEMBLY___PICKEDSURF166_SNEG

*Elset, elset=ASSEMBLY___PICKEDSURF167_S1

*rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

*rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

*rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

*rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

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*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF119

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF123

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF163

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF164
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   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF166

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF167

   *rigidbody,     refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,     elset=ASSEMBLY_RIGID1-
1_RIGID1-1

   *rigidbody,     refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,     elset=ASSEMBLY_RIGID2-
1_RIGID2-1

   *rigidbody,     refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,     elset=ASSEMBLY_RIGID3-
1_RIGID3-1

   *rigidbody,     refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,     elset=ASSEMBLY_RIGID4-
1_RIGID4-1

   *contactpair, interaction=INTPROP-1

   *contactpair, interaction=INTPROP-1

   *contactpair, interaction=INTPROP-1

   *contactpair, interaction=INTPROP-1

   *contactpair, interaction=INTPROP-1

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   *contactpair, interaction=INTPROP-1

   *tie, name=CONSTRAINT-1, adjust=YES

   *tie, name=CONSTRAINT-2, adjust=YES

   *tie, name=CONSTRAINT-3, adjust=YES

   *tie, name=CONSTRAINT-4, adjust=YES

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF119

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF120

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF121

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF122

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF123

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF124

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF125

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF126

   *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF127
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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF128

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF129

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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF165

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF166

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF167

*surfaceinteraction, name=INTPROP-1

*contactpair, interaction=INTPROP-1


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*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1
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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

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*contactpair, interaction=INTPROP-1

*material, name=GYPSUM

*density

*elastic

*material, name=TIMBER

*density

*elastic, type=ENGINEERINGCONSTANTS

*surfaceinteraction, name=INTPROP-1

*friction

*surfaceinteraction, name=INTPROP-1

*connectorbehavior, name=CONNPROP-1

*connectorelasticity, component=1

*connectorelasticity, component=2

*connectorelasticity, component=3

*orientation, name=ASSEMBLY_STUD1-1_ORI-2

*orientation, name=ASSEMBLY_STUD2-1_ORI-2

*orientation, name=ASSEMBLY_STUD3-1_ORI-2

*orientation, name=ASSEMBLY_STUD4-1_ORI-2

 *solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

 *solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

 *solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

 *solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

 *shellsection, elset=ASSEMBLY_CLADDING1-1__I1, material=GYPSUM
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*shellsection, elset=ASSEMBLY_CLADDING2-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING3-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING4-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING5-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING6-1__I1, material=GYPSUM

*rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

*rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

*rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

*rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

*rigidbody,    refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,    elset=ASSEMBLY_RIGID1-
1_RIGID1-1

*rigidbody,    refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,    elset=ASSEMBLY_RIGID2-
1_RIGID2-1

*rigidbody,    refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,    elset=ASSEMBLY_RIGID3-
1_RIGID3-1

*rigidbody,    refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,    elset=ASSEMBLY_RIGID4-
1_RIGID4-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

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*contactpair, interaction=INTPROP-1

*contactpair, interaction=INTPROP-1

*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*boundary
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*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

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*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*contactpair, interaction=INTPROP-1


*solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD1-1__I1,    orientation=ASSEMBLY_STUD1-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD2-1__I1,    orientation=ASSEMBLY_STUD2-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD3-1__I1,    orientation=ASSEMBLY_STUD3-1_ORI-2,
material=TIMBER

*solidsection,    elset=ASSEMBLY_STUD4-1__I1,    orientation=ASSEMBLY_STUD4-1_ORI-2,
material=TIMBER

*shellsection, elset=ASSEMBLY_CLADDING1-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING2-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING3-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING4-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING5-1__I1, material=GYPSUM

*shellsection, elset=ASSEMBLY_CLADDING6-1__I1, material=GYPSUM

*surfaceinteraction, name=INTPROP-1
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*contactpair, interaction=INTPROP-1




 *rigidbody,     refnode=ASSEMBLY_RIGID1-1_RIGID1-1-REFPT_,     elset=ASSEMBLY_RIGID1-
1_RIGID1-1

 *rigidbody,     refnode=ASSEMBLY_RIGID2-1_RIGID2-1-REFPT_,     elset=ASSEMBLY_RIGID2-
1_RIGID2-1

 *rigidbody,     refnode=ASSEMBLY_RIGID3-1_RIGID3-1-REFPT_,     elset=ASSEMBLY_RIGID3-
1_RIGID3-1

 *rigidbody,     refnode=ASSEMBLY_RIGID4-1_RIGID4-1-REFPT_,     elset=ASSEMBLY_RIGID4-
1_RIGID4-1

 *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF119

 *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF120

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 *surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF160
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*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF166

*surface, type=ELEMENT, name=ASSEMBLY__PICKEDSURF167

*tie, name=CONSTRAINT-1, adjust=YES

*tie, name=CONSTRAINT-2, adjust=YES

*tie, name=CONSTRAINT-3, adjust=YES

*tie, name=CONSTRAINT-4, adjust=YES

*connectorsection, elset=ASSEMBLY__CONN-10_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-100_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-101_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-102_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-103_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-104_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-105_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-106_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-107_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-108_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-109_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-11_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-110_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-111_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-12_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-13_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-14_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-15_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-16_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-17_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-18_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-19_CNSET_, behavior=CONNPROP-1
```

```
*connectorsection, elset=ASSEMBLY__CONN-20_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-21_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-22_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-23_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-24_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-25_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-26_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-27_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-28_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-29_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-30_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-31_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-32_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-33_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-34_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-35_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-36_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-37_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-38_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-39_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-40_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-41_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-42_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-43_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-64_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-65_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-66_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-67_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-68_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-69_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-70_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-71_CNSET_, behavior=CONNPROP-1
*connectorsection, elset=ASSEMBLY__CONN-72_CNSET_, behavior=CONNPROP-1
```

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*connectorsection, elset=ASSEMBLY__CONN-73_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-74_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-75_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-76_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-77_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-78_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-79_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-8_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-80_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-81_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-82_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-83_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-84_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-85_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-86_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-87_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-88_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-89_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-9_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-90_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-91_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-92_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-93_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-94_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-95_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-96_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-97_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-98_CNSET_, behavior=CONNPROP-1

*connectorsection, elset=ASSEMBLY__CONN-99_CNSET_, behavior=CONNPROP-1

*Step, name=conection

*output, field, variable=PRESELECT

*output, history

*Step, name=load
```

```
*output, field, variable=PRESELECT

*output, history

*Step, name=conection

*Step, name=load

*Step, name=conection

*static

*monitor, dof=3, node=ASSEMBLY_SET-1, frequency=1

*output, field, variable=PRESELECT

*output, history

*elprint, frequency=999999

*endstep

*Step, name=load

*static

*output, field, variable=PRESELECT

*output, history

*endstep

*boundary

*Step, name=conection

*static

*cload

*cload

*cload

*cload

*cload

*cload

*cload

*cload

*output, field, variable=PRESELECT

*output, history

*nodeoutput, nset=ASSEMBLY_SET-1

*nodeprint, frequency=999999

*endstep
```

```
 *Step, name=load

*static

*output, field, variable=PRESELECT

*output, history

*nodeoutput, nset=ASSEMBLY_SET-1

*endstep
```