M_W=8.0 Mandi Earthquake Disaster Scenario for Disaster Risk Management

RAPID VISUAL SCREENING OF BUILDINGS FOR POTENTIAL SEISMIC VULNERABILITY AND CONDITION ASSESSMENT

Submitted to

National Disaster Management Authority,

Government of India

Ravi Sinha, CVR Murty, Alok Goyal,
Ashish Sapre and Chaitanya Krishna
Indian Institutes of Technology at Bombay & Madras

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Introduction

Rapid Visual Screening is a simple procedure implemented to assess the ability of a structure against a potential seismic hazard. The evaluation is done on the basis of simple visual inspection. The basic idea of the procedure is to shortlist those buildings for which further assessment would be required.
The most important feature of this method is the simplicity in assessment of a building just by visual inspection of the building in the site. The method assigns damage to the building on the basis of visual evaluations and each member safety is assessed from calculations.

The RVS would be carried out for the list of buildings obtained from the district authorities and departments. The feature identity database would consist of minimal information of the buildings such name, utility of the building, address, location, person in charge of the building, etc. This would be used for filling the basic identification information in the RVS sheets.

The survey of buildings would be based on the forms in Appendix A. The forms are user friendly and require engineering knowledge to fill each sections of damage category and assess the safety levels of a building.

Evaluation Form Details

In this method of assessment, the most damaged load carrying members needs to be examined. In case some damaged load carrying members cannot be examined due to absence of safe access or other similar reasons, suitable conservative assumptions need to be made regarding the status of those members.

The safety assessment form is divided into five sections:

Section A:

This section requires the general information of the survey team, date, location and other details of the building

Section B:

This section requires general information about the building such as occupancy, soil and site conditions of the building.

Section C:

This section is the main survey portion for collecting all the necessary information about the current structural condition of the building. This section is divided into four subsections. It may be noted that old buildings may experience collapse or failure on any floor of the building. The survey of the vertical and horizontal load-resisting members should therefore be carried out on all floors of the building. The form has been designed so that one sheet of survey information on vertical and horizontal members can be filled for each floor of the building.

The various sub-sections of Section C as described below:

Subsection-1: Overall structural observation of the building. If the building is found to be obviously unsafe it should be categorized as S5 and no further survey is required.

Subsection-2: Assessment of unequal settlement of the columns/walls or other manifestation of foundation weakness.

Subsection-3: Assessment of distress in vertical load carrying members of each floor of the building. **One page is required to be filled for each floor.** Buildings might be composite in nature; hence different kind of vertical members like load-bearing walls, RCC/steel/wooden columns are included in this section. The Building Condition Assessment Engineer should mark only the relevant part of subsection for a particular building. The form requires filling of the condition of elements in terms of structural damage category (S0 to S5). When the number of members/elements of a particular kind is asked (to categorize as S0-S1, S2-S3, S4 or S5) the exact number of members should be filled only if their number is very low. When more than a few members are of a particular category, they should be filled as All, Most or Many. Here "Most" indicates more than 70% of total observed members and "Many" indicates 40% to 70% of total observed members. For example, if on a particular floor in a building 40 columns are evaluated; out of these, 7 are category S5, 0 are categorized as S4, 20 are category S2-S3 and rest in S0-S1 category. Then S5 category should be filled as "7", S4 category should be filled as "0" and S2-S3 and S0-S1 should be filled with "many". The guidelines to decide the element category are given in Appendix B

Subsection-4: Assessment of distress in horizontal load carrying members of each floor of the building. **One page is required to be filled up for each floor in Subsection-4**. Buildings may be composite in nature, hence different kind of beam members like RCC, steel and timber are included in this section. The Building Condition Assessment Engineer should mark only the relevant part of subsection for a particular building. Form requires filling the condition of elements in terms of structural damage category (S0 to S5). The guidelines to decide the element category are given in Appendix B.

Terms used in the form:

Mud Mortar: Mortar made of clay, sand or gravel and water.

Lime Mortar: Mortar made of lime, sand and water.

Cement Mortar: Mortar made of cement, sand and water.

Gauge mortar: Mortar made of Plaster of Paris used either pure or with lime or lime and sand.

Piers: Any of various vertical supporting structures, especially:

A pillar, generally rectangular in cross section, supporting an arch or roof.

The portion of a wall between windows, doors, or other openings.

A reinforcing vertical structure that projects from a wall; a buttress.

Voussoir: Wedge shaped masonry unit in an arch.

Keystone: Central Voussoir

Bulging: Local thickening of masonry wall because of excess load.

Spalling of concrete: Falling of cover concrete because of poor concrete quality or corrosion of reinforcement.

Hinge formation: Loss of moment transfer capacity of a beam-column joint.

Bracing: System of structural members, usually diagonal, that act in compression or tension and stiffens a structure.

Knee Bracing: Inclined bracing usually to support cantilever beams or beams with long span.

Bowing of column: Bending of column in shape of a bow due to excessive load.

Condition of horizontal structural elements

Chord: Any beam that is curved in plan.

Girder/Binder: A beam of steel, wood, or reinforced concrete, used as a main horizontal support in a building.

Joist: Any of wood, steel, or concrete beams set parallel from wall to wall or across or abutting girders to support a floor or ceiling.

Punching shear: Stress imposed on a structural member by a load tending to penetrate that member.

Vault: An arched structure, usually of masonry or concrete, serving to cover a space.

Tie: A steel tension member provided to avoid lateral force on joist web.

After the damage assessment, is the evaluation of status of vertical structural members, namely RCC/timber/steel columns and masonry wall. Dimensions of these members are noted and using the graphs, given in Appendix C, the capacity of the member is calculated. The existing capacity is compared with the actual loading on the member and member condition is decided as safe or unsafe.

Similarly the evaluation status of horizontal structural members. These members include Jack Arch Floor, RCC slab (one-way and two-way), and RCC/timber/steel beams. The dimensions and load carrying capacity of the members is found out using the graphs prepared for this purpose and compared with existing load.

Section E

This section of the form is a summary of evaluation where the number of safe and unsafe structural members would be written for each floor.

The overall assessment of the building is to be done on the basis of capacity of the building, which is interpreted on the basis of table in Appendix B.

Structural Element Description

Now we discuss the building structural elements, their function, distress and safety issues related to each element.

Slab/Floor

A structure facilitating to cater different human needs and slabs are the structural elements, which carry the vertical forces generated by such activities and transfer them to other elements such as beam or wall. Slabs are designed to carry certain amount of shear and moment. Slab material and thickness decide its load carrying capacity. Following are the main type of slab/floor generally constructed in a building:

Timber Floor

Wooden planks are placed over timber joists perpendicular to the span of the joists. Planks are fastened to joists with the help of nails. PCC flooring is provided over planks to make the surface continuous and waterproof. Typically these joists are placed at an interval of one to two feet and cross section is 50x100mm. to 75x125mm.

Figure 1 Timber flooring on timber joists

Distress in Timber Slab

Cracks in the slab indicate the excessive amount of load on the floor. Sloping of floor indicates unequal settlement of supporting walls or columns, deterioration of supporting beam or disintegration of joists at ends. Distress in the slab can be noted by observing tilted or cracked floor tiles, visible sagging of supporting joists etc.

Safety Issues in Timber Slab

Distressed floors are a point of concern for the safety of the occupant. Falling pieces from flooring, sudden failure of supporting joists, etc., pose danger of injury or death for residents. Failure of entire slab panel may trigger progressive collapse if the slabs at lower floors are also deteriorated.

Jack Arch Floor

This type of flooring is supported by arches. Arches are made of brick or stone. Arch ends are supported on steel joists. Sometimes ties are provided at regular intervals. Tie bars are tension members, which carry tension to avoid lateral force from arch to arch supporting joists. Floor surface is made horizontal by filling with earthwork and concrete cover. Rise of such arch is of the order of 50 to 100 mm depending on the arch span. Over the arch crown generally one inch thick PCC layer is provided.

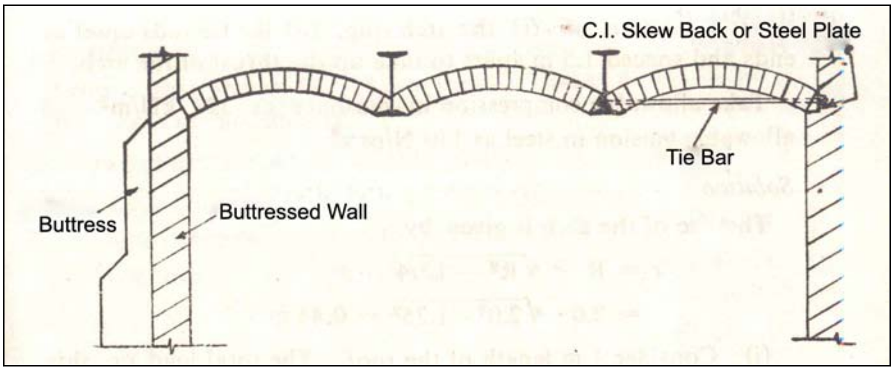


Figure 2:Jack arch floor (*Source: Masonry and Timber Structures including Earthquake Resistance Design by Arya*)

Distress in Jack Arch Floor

Cracks in the slab indicate the excessive amount of load on the floor. Sloping of floor indicates unequal settlement of supporting walls or columns, deterioration of supporting beam or disintegration of joists at ends. Distress in the slab can be noted by observing tilted or cracked floor tiles, visible sagging of supporting joists etc. Main part of jack arch slab is the keystone. Condition of the keystone and neighbouring voussoir is important to observe. Loosening or failure of keystone leads to failure of arch action, which as a result, increases chance of total or part collapse of arch and slab eventually.

Safety Issues in Jack Arch Floor

Distressed floors are a point of concern for the safety of the occupant. Falling pieces from flooring, sudden failure of supporting joists, etc., pose danger of injury or death for residents. Failure of entire slab panel may trigger progressive collapse if the slabs at lower floors are also deteriorated.

Ladi-Coba slab

This type of flooring is done by supporting stone blocks on steel joists. The stone slab is called Ladi. The floor is provided with 75 mm layer of plain cement concrete (PCC). Above this PCC layer one more layer of Ladi is provided for floor finish. This entire system of Ladi-coba floor rests on steel joists, which are generally ISMB125. These joists transfer their load to beams on which they are resting.

Figure 2 Ladi-Coba slab components

Distresses in Ladi-Coba slab

This type of slab shows undulation, sagging or cracking because of support sagging or displacement. Improper maintenance of steel joists and excessive loading on the floor are the main cause of distresses in the joists. Structural safety of Ladi-Coba flooring can be judged by inspecting the joists which support the floor. If the joists are intact, only local failure of floor can occur because of cracks in stone, failure of PCC layer etc.

Safety Issues in Ladi-Coba slab

Local failure of floor may be sudden because of brittle nature of Ladi and PCC. But if the entire floor fails it will typically occur after visual warning of excessive sagging or failure at supports. In such cases residents may get sufficient time to move out of the building.

Cast-Stone (Precast RCC blocks) Floor

Precast concrete floors are called cast-stone slab. These RCC segments are cast in the factory and after curing placed on the joists. These panels look like a series of arch and joists (as can be seen in the picture below). Load transfer mechanism is same as any other joists supporting slab system. Load on the floor is transferred to the RCC joist, a part of precast slab, and from joists load is transferred to main beam or load bearing wall. This construction practice came into existence in mid 1990s, when original timber floors were replaced by these precast slabs in a large number of buildings undergoing rehabilitation.

Figure 3 Cast-Stone Slab

Distress in Caststone Floor

Cracks in the slab indicate the excessive amount of load on the floor. Sloping of floor indicates unequal settlement of supporting walls or columns, deterioration of supporting beam or disintegration of joists at ends. Distress in the slab can be noted by observing tilted or cracked floor tiles, visible sagging of supporting joists etc. Exposed reinforcement is a common observation in deteriorated precast concrete slab, which indicates water seepage in slab and reduced capacity of slab. In RCC slab reinforcement may be exposed because of falling of concrete cover at the lower face of slab. This kind of concrete spalling is observed generally in common toilet and washing area or common passage of building.

Safety Issues in Caststone Floor

Distressed floors are a point of concern for the safety of the occupant. Falling pieces from flooring, sudden failure of supporting joists, etc., pose danger of injury or death for residents. Failure of entire slab panel may trigger progressive collapse if the slabs at lower floors are also deteriorated.

Hollow Concrete Block Floor

This kind of flooring is also a precast RCC blocks. These blocks are hollow to make them lightweight. Precast blocks are placed over joists or beam and cemented to make them waterproof.

Figure 4 Hollow Concrete Block Floor

Figure 5 Hollow concrete block floors resting on RCC joists

Distress in Hollow Concrete Block Floor

Cracks in the slab indicate excessive amount of load on the floor. Sloping of floor indicates unequal settlement of supporting walls or columns, deterioration of supporting beam or disintegration of joists at ends. Distress in the slab can be noted by observing tilted or cracked floor tiles, visible sagging of supporting joists etc. Exposed reinforcement is a common observation in deteriorated precast concrete slab, which indicates water seepage in slab and reduced capacity of slab. In RCC slab reinforcement may be exposed because of falling of concrete cover at the lower face of slab. This kind of concrete spalling is observed generally in common toilet and washing area or common passage of building.

Safety Issues in Hollow Concrete Block Floor

Distressed floors are a point of concern for the safety of the occupant. Falling pieces from flooring, sudden failure of supporting joists, etc., pose danger of injury or death for residents. Failure of entire slab panel may trigger progressive collapse if the slabs at lower floors are also deteriorated.

RCC Slab

RCC slabs are designed to carry certain amount of shear and moment load. Bottom reinforcement is designed to carry tension and vertical stirrups are designed to carry shear force. Sufficient thickness of cover concrete is required to avoid rusting of reinforcement.

Figure 6Spalling of slab cover concrete

Distress in RCC Slab

Cracks in the slab indicate the excessive amount of load on the floor. Sloping of floor indicates unequal settlement of supporting walls or columns, deterioration of supporting beam or disintegration of joists at ends. Distress in the slab can be noted by observing tilted or cracked floor tiles, visible sagging of supporting joists etc. Exposed reinforcement is a common observation in deteriorated precast concrete slab, which indicates water seepage in slab and reduced capacity of slab. In RCC slab reinforcement may be exposed because of falling of concrete cover at lower face of the slab. This kind of concrete spalling is observed generally in common toilet and washing area or common passage of building.

Sometimes RCC slabs have cut-outs because of functional requirement. But not all cavities constructed in the slab are cut outs. Cut-outs in the slab are structurally significant when they start influencing structural behaviour such as deflection pattern, yield-line etc. In general the cut-out area must exceed 5% of slab area to be considered as significant for the purpose of the Safety Assessment Form. Even smaller cut-outs may be structurally significant depending on its location if it influences the slab behaviour.

Safety Issues in RCC Slab

Distressed floors are a point of concern for the safety of the occupant. Falling pieces from flooring, sudden failure of supporting joists, etc., pose danger of injury or death for residents. Failure of entire slab panel may trigger progressive collapse if the slabs at lower floors are also deteriorated.

Joist

Joists are the members that carry load from floor and transfer it to wall or beam. Joists are placed at a regular interval of 1-2 feet. Joists are designed to carry shear and bending moment if ends are fixed or only shear if simply supported. Joists that support arched floor are also designed to carry lateral loads. Joists can be of timber or steel. Although both type of joists serve same purpose, their distress are very different.

Timber Joist

Distress in Timber Joists

Timber joists disintegrate at support due to weathering or termites. This causes reduction in shear and moment carrying capacity. Weathering effect on the hidden part of joists is not very easily visible if the joists are embedded in the wall or beam. Timber joists are prone to sudden failure without any warning. Hence these joists should be observed with care, to note any secondary effect like floor tilting, cracks in the floor etc.

Figure 7Weathering of timber joists at support

Safety Issues in Timber Joists

Joists are embedded in the load bearing wall or timber beam for support. Deterioration of such joists is difficult to assess. Sudden failure of such joists may cause injury or death to residents. Timber joists are more prone to failure without indication. Steel joists show sufficient amount of rusting or displacement prior to failure. Joists that are hidden in the loft/false ceiling and/or storeroom put more safety challenge, as the degradation is not visible to residents on a day-to-day basis.

Steel Joist

Distress in Steel Joists

Steel joists have problem of rusting. Rusting may occur anywhere in joist. Generally top flange and web of the joist are embedded in the floor and only bottom flange is available for inspection (as shown in the Fig-8). Rusting reduces shear and moment carrying capacity of joist. Steel joists have less probability of sudden collapse because of plastic nature of steel beyond its elastic limit. Steel joists show sufficient amount of deflection before failure. Sudden collapse may occur in case of joint failure with beam, where joists are heavily rusted or welding has failed.

Figure 8 Rusting of steel joists (Only bottom flange is available for inspection)

Safety Issues in Steel Joists

Joists are embedded in the load bearing wall or timber/steel beam for support. Deterioration of such joists is difficult to assess. Sudden failure of such joists may cause injury or death to residents. Timber joists are more prone to failure without indication. Steel joists show sufficient amount of rusting or displacement prior to failure. Joists that are hidden in the loft/false ceiling and/or storeroom put more safety challenge, as the degradation is not visible to residents on a day-to-day basis.

Beam

Beam carries load from joists and transfer it to vertical load carrying member, wall or column. Beams are designed for transferring shear and bending moment. Beam can be made of timber, steel or RCC. Each type has particular kind of distress. Beams support large number of joists and hence their effective area of influence is more than a joist but less than a column.

Timber Beam

Distress in Timber Beam

Timber beams, similar to timber joists, are prone to weathering. Moreover, if the beams are embedded in wall, it is difficult to access the condition of beam unless the deterioration is at a level such that it is visible from outside or has notable effects like separation of joists or tilting of upper story wall. Timber beams have tendency to decay fast because of water seepage. This kind of distress is more prominent in common toilet or washing area, where water seepage is more because of improper maintenance.

Figure 9 Sagging and support displacement of timber beam

Safety Issues in Timber Beam

Beams support large area of slab and hence proper maintenance and inspection of beams is very important. Sudden failure of slab because of beam failure may put many lives at risk. It is easier to assess the distress in RCC beam compared to steel or timber, especially if embedded in wall.

Steel Beam

Distress in Steel Beam

Steel beams are prone to rusting if poorly maintained, which is the case in general for common area. Sometimes steel beam rests on timber column or a load bearing wall to transfer load, this difference of material causes extra stress at the interface of two. Following is an example of rusted beam resting on a timber column.

Figure 10 Steel beam on timber column

Safety Issues in Steel Beam

Beams support large area of slab and hence proper maintenance and inspection of beams is very important. Sudden failure of slab because of beam failure may put many lives at risk. It is easier to assess the distress in RCC beam compared to steel or timber, specially if embedded in wall.

RCC Beam

Distress in RCC Beam

RCC beams show distress because of various reasons. Poor concrete quality is one of the primary reasons of failure/dilapidation of such beams. Reinforcement bars deteriorate at a faster rate if adequate thickness of cover concrete is not available for protection. Bottom portion of beam at midspan is in tension and hence vertical tension cracks are common there, rising from bottom to top. On the other hand, ends of beam have tension at top and vertical cracks originate at top and progress to bottom. Shear cracks are generated because of heavy load on floors. These cracks are generally found near support and inclined at approximately 45 degrees.

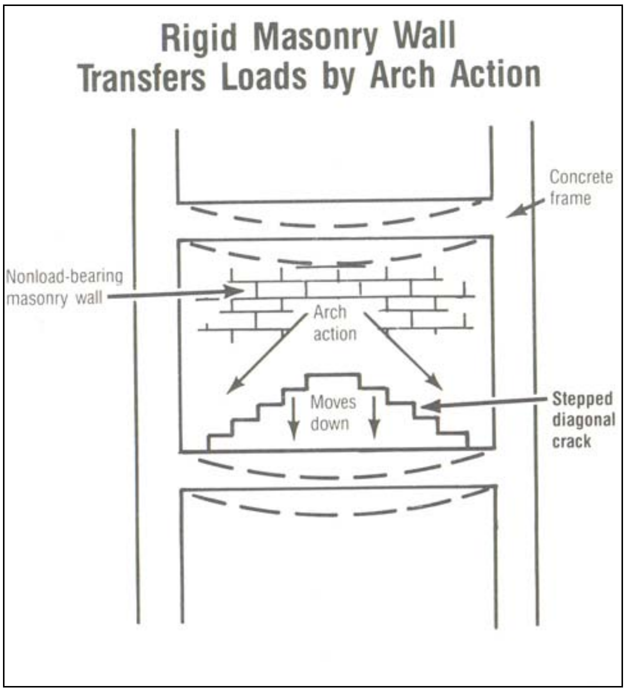


Figure 11 Load transfer through beam and masonry wall (*Source: Nondestructive evaluation & testing of masonry structures by Suprenant andSchuller*)

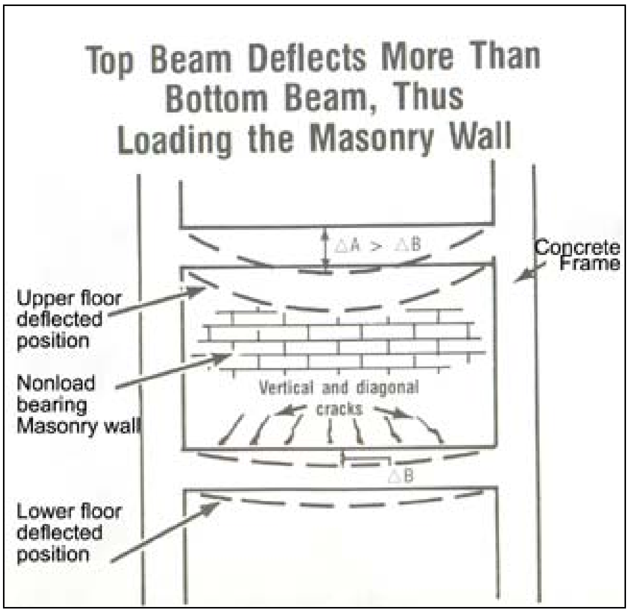


Figure 12 Beam crack due to excessive load (*Source: Nondestructive evaluation & testing of masonry structures by Suprenant and Schuller*)

Figure 13Concretespalling at the bottom of beam because of tension

Safety Issues in RCC Beam

Beams support large area of slab and hence proper maintenance and inspection of beams is very important. Sudden failure of slab because of beam failure may put many lives at risk. RCC slab and RCC beam are cast together during construction, so it is a relatively safe construction compared to wooden or steel beam where slabs are separate entity from beam. It is easier to assess the distress in RCC beam compared to steel or timber, specially if embedded in wall.

Load Bearing Wall

Function of Load Bearing Wall

Load bearing walls are main component of load bearing structures. Walls carry the entire load from beam/joists and transfer it to foundation. Walls are designed to carry vertical as well as some amount of lateral load. Lateral load carrying capacity is enhanced by providing buttress at regular interval. Walls can be made of brick, stone or mixed rubble. Strength of wall depends on strength of brick/stone as well as binding mortar. These walls have openings for windows and doors. Such openings generally have arch. Different components of an arch are shown in following diagram:

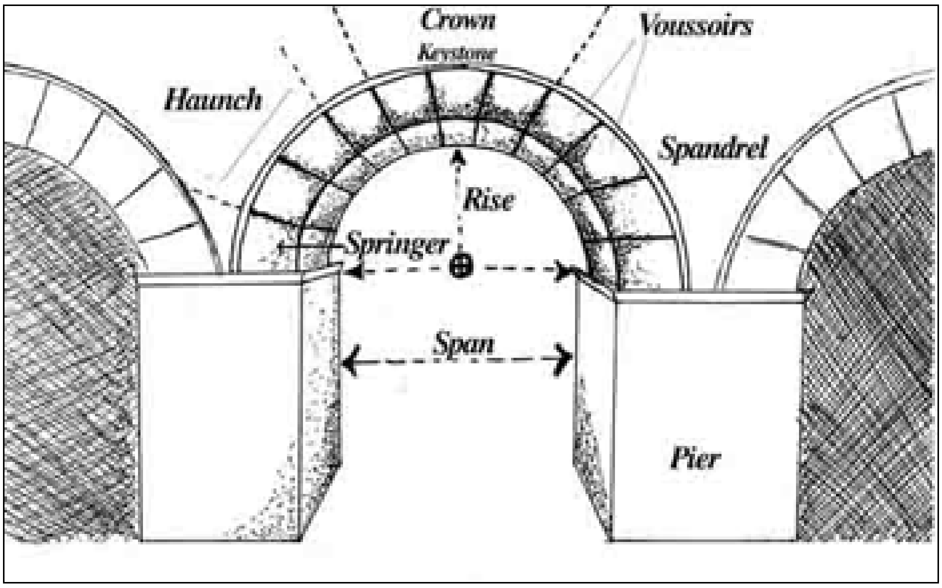


Figure 14 Arch component (*source: http://www.usi.edu/artdept/artinindiana/Glossary/images/arch.jpg*)

Distress in Load Bearing Wall

Walls are damaged because of various reasons. Differential settlement at foundation level is one cause of damage of wall. Wall cracks are of two types: vertical and cross or diagonal. Vertical cracks are caused by differential settlement, excess vertical load or movement of perpendicular walls in different direction. Diagonal or cross cracks develop due to lateral forces such as earthquake load.

Figure 15 Separation of walls

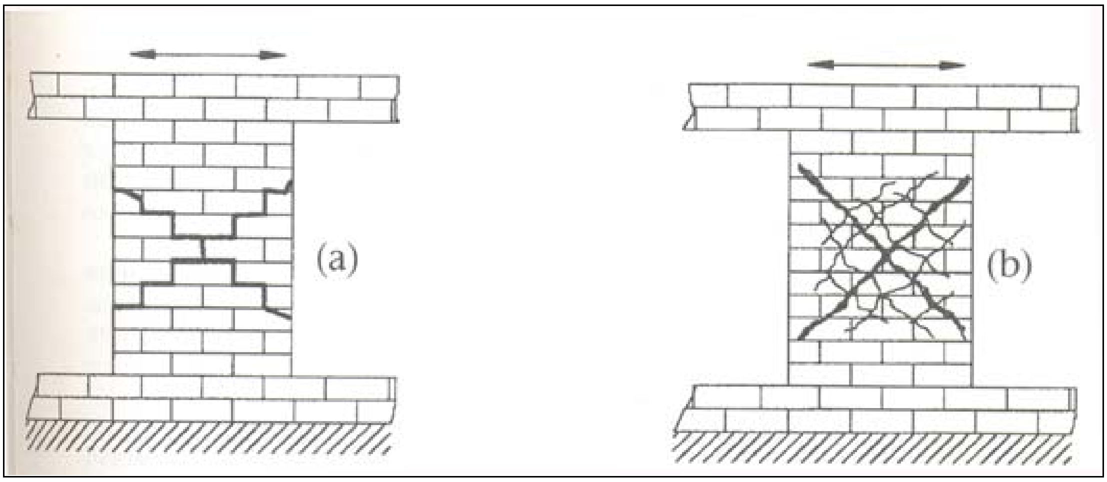


Figure 16 Shear crack development in (a) unreinforced masonry and (b) reinforced masonry (*Source: Nondestructive evaluation & testing of masonry structures by Suprena and Schuller*)

Figure 17 - Vertical crack in load bearing wall

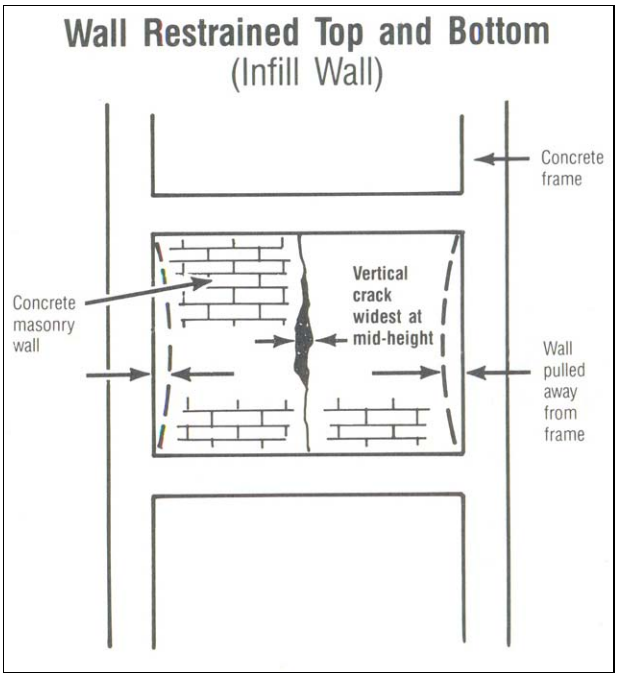


Figure 18 Wall crack due to shrinkage of mortar and concrete masonry unit (*Source: Nondestructive evaluation & testing of masonry structures by Suprenant and Schuller*)

Other kind of wall damage includes bulging of wall, tilting of wall and wall settlement. Wall bulging is the phenomenon where wall thickness increases at certain locations due to high loading. Material of wall starts loosing bond and being pushed in outward direction due to load. Tilting of wall is the result of lateral force or tilting of foundation itself. Foundation settlement causes unequal settlement of building, which causes tilting of beam, joists and eventually of slab.

Arched opening are very important and critical. Arches are cracked because of high load or weak binding mortar. Crown crack, a crack in adjacent to keystone, is sign of failure of arch. Other cracks or failure of voussoir (masonry units of arch) are also dangerous.

Figure 19Voussoir crack

Safety Issues in Load Bearing Wall

Walls are the main component of load bearing structure. Distressing or collapse of a wall panel may cause collapse of entire building. Severely distressed wall cannot retain slab weight effectively and hence poses the danger of slab collapse. If a particular wall is in very dilapidated condition, its load is transferred to adjacent walls, which may cause their early decay.

Column

Timber Column

Function of Timber Column

Column transfers vertical load to ground from beam. This is the most crucial element of frame structure. Columns are designed to carry axial load and moments, sometimes in both the direction. Central column supports minimum four beams hence a large area depends on the performance of such column.

Distress in Timber Column

Timber columns degenerate due to weathering effects, termite action, excessive loading etc. Sometimes, column decays from inside and it is difficult to judge the extent of decay from visual observation. Actual condition is known only after significant decay or failure of column. Beam-column junction is the most important part to be observed. Effectiveness of load transfer from beam to column is decided by strength of junction. Distressed junction will not be able to fully transfer the load and hence column will remain underutilised and beam will be overstressed.

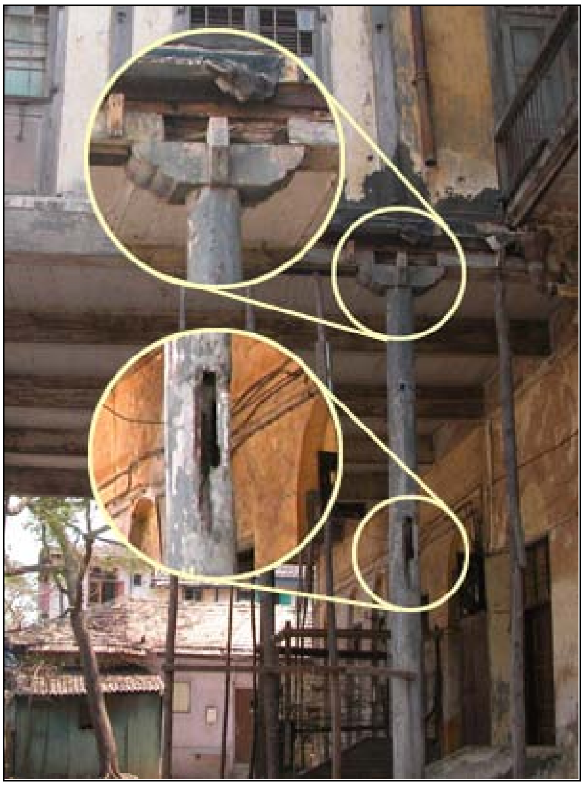


Figure 20 Reduced cross-section area and deteriorated beam-column junction of timber column

Safety Issues in Timber Column

Column supports a large area and hence is of primary importance. Any damage or collapse of column may trigger the collapse of entire building, depending upon its location and condition of adjacent columns. In a frame structure virtually entire structure acts as a single unit. During the design phase care is taken to provide adequate redundancy in the structure. So the load is already distributed to other columns when a column is weak compared to others, but in an old and dilapidated structure all the columns have same age and almost all are equally weak or strong. So sudden collapse of any one column may trigger progressive collapse. For this reason it is very important to check all columns carefully.

Steel Column

Function of Steel Column

Column transfers vertical load to ground from beam. This is the most crucial element of frame kind of structure. Columns are designed to carry axial load and moments, sometimes in both the direction. Timber and steel frame structure are functionally same but behaviourally different because of different material property of timber and steel.

Distress in Steel Column

Steel columns degenerate due to weathering effects, which is visible in form of rusting. Beam-column junction is the most important part to be observed. Effectiveness of load transfer from beam to column is decided by soundness of junction. Distressed junction will not be able to fully transfer the load and hence column will remain underutilised and beam will be overstressed. Column support should also be observed carefully for steel columns. Condition of gusset plates, anchor bolts, welding and other details show the effectiveness of column in terms of load carrying capacity. Amount of rusting of column is directly proportional to reduction in the weight carrying capacity.

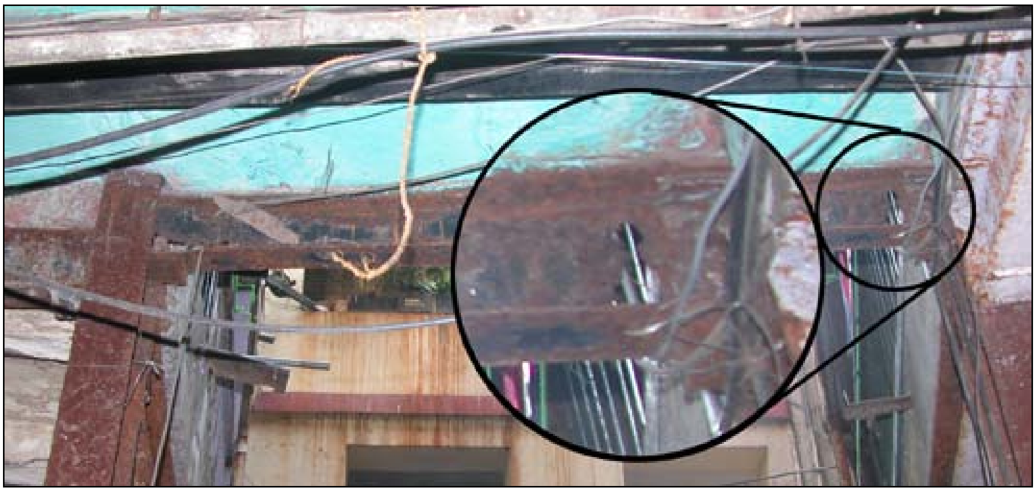


Figure 21 Ineffective beam-column junction

Figure 22 Reduced cross-section area of steel column

Safety Issues in Steel Column

Column supports a large area and hence is of primary importance. Any damage or collapse of column may trigger the collapse of entire building, depending upon its location and condition of adjacent columns. In a frame structure virtually entire structure acts as a single unit. During the design phase care is taken to provide adequate redundancy in the structure. So the load is already distributed to other columns when a column is weak as compared to others, but in an old and dilapidated structure all the columns have same age and almost equally weak or strong. So sudden collapse of any one column may trigger progressive collapse. For this reason it is very important to check all columns carefully.

RCC Column

Function of RCC Column

Columns receive load from beam and transfer it to foundation. Columns are designed to carry axial load and bending moment in two directions. Reinforcement bars increase the load carrying capacity of column as well as take tension if there is excessive bending moment. Stirrups keep entire core concrete intact and increase shear strength of column. It is important to have sufficient amount of cover concrete in order to avoid decay of reinforcement.

Distress in RCC Column

One of the distress in RCC column is spalling of outer layer of concrete and exposed reinforcement. Exposed reinforcement is affected by atmosphere at a faster rate. Reinforcement is also affected by atmosphere if there is vertical or cross crack in column. These kinds of cracks are induced because of excessive load on the column. Column buckling is another type of distress, which shows excessive load on column. Beam-column junction is a crucial part for observation. Soundness of this portion indicates good load transfer mechanism of frame structure.

Figure 23 Spalling of cover concrete and buckling of reinforcement bars

Safety Issues in RCC Column

Column supports a large area and hence is of primary importance. Any damage or collapse of column may trigger the collapse of entire building, depending upon its location and condition of adjacent columns. In a frame structure virtually entire structure acts as a single unit. During the design phase care is taken to provide adequate redundancy in the structure. So the load is already distributed to other columns when a column is weak as compared to others, but in an old and dilapidated structure all the columns have same age and almost equally weak or strong. So sudden collapse of any one column may trigger progressive collapse. For this reason it is very important to check all columns carefully.

Estimation of Loads

Slabs

Assumptions

The following assumptions have been made during the development of graphs for jack arch slab:

1) Calculations for the jack arch floor are based on working stress method.
2) Graphs are valid for the floor where there is no substantial concentrated load on the floor. Concentrated loads may change the stress distribution on the floor, leading towards different mode of failure as against assumed mode of crushing of masonry at the support of jack arch floor.
3) The masonry strength is assumed to be 0.3 MPa.
4) Calculations are valid for R/l ratio (rise to span ratio) between 1/8 and 1/12.
5) Calculations are carried out for a rise by span ratio (R/l) of 1/12.
6) Graphs are prepared for two thickness values of the floor: 115 and 230 mm based on information available for buildings.

The following assumptions have been made during the development of safety charts for RCC slab:

1) Calculations for design of RCC slabs are based on limit state method.
2) Minimum reinforcement of 0.12% (as per IS code) is assumed in the slab for calculation and preparation of the graphs. One more set of calculations are done for 0.2% reinforcement.

3) One-way slabs are designed as unit width beam, so b=1000 mm.

4) Two different charts are presented for reinforcement steel grades of 250MPa and 415MPa.

5) Charts are valid for concrete grade from M10 to M40.

6) Concrete cover of 25mm is assumed in the calculations.

Methodology

Slabs directly support the imposed loads in a building. It has been found that slabs can be overloaded due to repeated flooring, bulk storage, heavy machinery, etc. Sometimes, the slabs are loaded from below by fixing hanging platforms etc. The slab should therefore also be inspected from below where such loading is suspected. The inspection of slabs should be started from the top floor. The portion of the building which is loaded very heavily and/or heavily deteriorated should be identified during the evaluation. Then the following steps should be followed to determine the capacity of the slab.

1) Determine the dimensions of the slab, length and width of the slab are the unsupported length between the beams. During the measurement of thickness of floor width, thickness of flooring should be subtracted from the total thickness. The remaining thickness is the effective thickness which helps in resisting loads.

2) Charts are provided in Appendix C for two thicknesses of the floor, 115 mm and 230 mm. Estimate allowable load for given thickness, arch span and allowable masonry strength of the chart. Now compare this allowable load with the existing load on the floor.

3) For the RCC slabs establish whether the floor is one-way or two-way depending on its aspect ratio. Then use appropriate chart from Appendix C. Find out the allowable floor load for given

thickness and span of the floor. Compare this load with the existing load on the floor.

4) If a slab portion is found unsafe, immediate steps should be taken to reduce load on the floor or to provide additional supports to the slab. Props should be provided to support it till the load is reduced and/or structural repair is carried out to improve its capacity. Propping system should be provided up to ground floor irrespective of the capacity of the slabs in lower floor below the weak floor.

Beams

Assumptions

The following assumptions have been made during the development of the safety charts for timber beam:

1) Calculations for the timber beam are based on working stress method.

2) Timber density is assumed as 640 kg/m^3 assuming Teak wood density as per IS: 875 (Part-1)-1987.

3) Beams are assumed as simply supported so that the mid span moment is maximum, which is being on conservative side.

4) Timber allowable stress is assumed as per IS 883:1994. Charts are prepared for six different values of allowable stresses: 7.5 MPa, 10 MPa, 12.5 MPa, 15 MPa, 20 MPa and 25 MPa.

The following assumptions have been made during the development of the safety charts for RCC beam:

1) Design calculations are based on limit state method.

2) Minimum reinforcement of 0.2% (as per IS code) is assumed in the beam for calculations and preparation of charts. additional charts are also prepared for 0.3% and 0.4% reinforcement.

3) Two different charts are prepared for steel grades of 250MPa and 415MPa.

4) Charts are valid for concrete grade of M10 to M40.

5) Concrete cover of 40mm is assumed in the calculations.

The following assumptions have been made during the development of the safety charts for steel beam:

1) Calculations are based on working stress method.

2) Allowable stress in steel is assumed to be $0.66f_y$. The steel grade is considered as 250MPa.

3) Charts are prepared for various ISMB sections specified in Steel Table.

4) Beams are assumed as simply supported for calculations.

Methodology

Beams take load from slabs and transfer it to column or load bearing wall. All beams which support the slabs should be examined and in addition, other beams which have deteriorated and/or sagging should also be checked. The following steps are used to assess the beam for evaluation:

1) Estimate the dimensions and span of the beam. The span of the beam is the clear distance between supports. Depth of the beam is easier to measure for timber beam. In case of RCC beam depth is the dimension from top surface of slab to bottom of the

beam. Section type should be found out if the beam is of steel and cross sectional properties obtained from steel table.

2) The allowable compressive strength of the timber should be taken as 7.5 MPa unless the type of timber is known. Using these three parameters (depth of beam, span and allowable compressive strength of the timber) find out the allowable dead load and superimposed dead load from the charts given in Appendix C. Charts are given for three beam widths (100 mm, 150 mm and 200 mm), six allowable stresses (7.5 MPa, 10 MPa, 12.5 MPa, 15 MPa, 20 MPa and 25 MPa) and six beam spans (2m, 2.5m, 3m, 4m, 6m and 8m). Estimate the load on the beam, which is sum total of loads from the contributing slabs and wall on the beam, if any. Compare the allowable load and estimated load and take appropriate actions if estimated load is greater than allowable load. Any beam that is fully resting on the load bearing wall for its full span should not be considered as a structural member and hence no calculations are required for these beams.

3) Repeat the above procedure for RCC beam. Charts of Appendix C are based on three parameters: beam depth (250 mm to 1000 mm), beam span (2m, 2.5m, 3m, 4m, 6m and 8m) and percent of tensile reinforcement (0.2%, 0.3% and 0.4%). Charts are valid for concrete grade M10 to M40. Calculate allowable load from chart and compare that load with estimated load on the floor. Any beam that is fully resting on the load bearing wall for its full span should not be considered as a structural member and hence no calculations are required for these beams.

4) Charts for steel beams are provided in Appendix C for beam span versus allowable load. Find out the allowable load and compare it with estimated load on the beam. Any beam that is fully resting

on the load bearing wall for its full span should not be considered as a structural member and hence no calculations are required for these beams.

Columns

Assumptions

The following assumptions have been made during the development of the safety charts for timber column:

1) Calculations for the timber column are based on working stress method.
2) Charts are valid for uni-axial bending case with bending along the major axis.
3) Timber stress-strain curve is assumed to be similar in tension and compression.
4) Charts are prepared for column sizes 5″x5″ (125x125mm), 6″x6″ (150x150mm), 7″x7″ (175x175mm), 8″x8″ (200x200mm), 10″x10″ (250x250mm) and 12″x12″ (300x300mm) and allowable stresses of 5MPa, 10MPa &15MPa.

The following assumptions have been made during the development of the safety charts for RCC columns:

1) All calculations are done using limit state method.
2) Minimum reinforcement of 0.8% (as per IS code) is assumed in the column for calculation and preparation of chart. Additionally reinforcement percentage of 1.0% and 1.2% have also been used.
3) These charts are not valid for slander columns where failure may be initiated due to buckling.

4) Clear cover is assumed as 0.1D.

5) Two different charts are prepared for reinforcement steel grades of 250MPa and 415MPa.

6) Charts are given for concrete grade M10, M15 and M20.

The following assumptions have been made during the development of the safety charts for steel column.

1) Calculations for steel column are based on working stress method.

2) Allowable stress in steel is $0.66f_y$. Steel grade is considered as 250MPa.

3) A uniform slenderness ratio of 40 is assumed for all the columns. For this reason the allowable stress for steel columns is 139 MPa as per IS: 800 – 1984.

4) Charts are valid for uni-axial bending case with bending along the major axis.

Methodology

Columns are the main vertical load carrying members in frame structure. All the columns that support excessively loaded slab and beams should be checked through this evaluation method. Also all the column that are showing significant rusting, bowing, buckling, reduction in cross section and/or concrete spalling should be examined. Guidelines to examine columns of the building are as follows:

1) Measure the dimension of the column. Width and thickness of any column are the minimum dimension at any section along the height of column for RCC and timber column. Note these dimensions (for RCC and timber columns) and height of column, which is the unsupported length between two stories.

2) Find out the load on the column, which is the sum of loads from all the upper stories and beams supported on it. Note that if the column is embedded in the load bearing masonry wall it is assumed that it does not carry any load. The entire load is transferred to the load bearing wall through beams. Estimate the moment along the major axis due to the beams on it. Now using the graph given in Appendix C check whether the moment is within allowable limit or not. Graphs are given for Axial Load and Moment along major axis.

3) Charts are prepared for timber column sizes 5″x5″ (125x125mm), 6″x6″ (150x150mm), 7″x7″ (175x175mm), 8″x8″ (200x200mm), 10″x10″ (250x250mm) and 12″x12″ (300x300mm). Timber capacity should be initially taken as 7.5 MPa for calculations unless the type of timber is known. Graphs for RCC columns are given for 250MPa and 415MPa reinforcement. The characteristic strength of the RCC column should be considered as 10 MPa. In case of steel section graph between axial load and moment are given, similar to timber column. Nine different types of steel sections are used to plot the PM curve for steel column.

Masonry Walls

Assumptions

The following assumptions have been made during the development of the safety charts for the masonry walls:

1) Calculations for the masonry wall are based on working stress method.

2) It is assumed that only axial load is applied on the walls as the stresses due to moments are negligible compared to axial stress.

Methodology

Masonry walls support beams and girders and transfer vertical loads to foundation. Strength of a wall mainly depends on two parameters, allowable stress on masonry units and wall thickness. Other factors affecting the load carrying capacity of wall are slenderness ratio, openings in the wall, eccentricity of loads etc. Following guidelines should be observed while checking the status of a masonry wall through this evaluation:

1) Measure the width of the wall, which is the minimum measurement of the section along the length and height of the wall. Any wall section between columns (timber or steel) and/or masonry pier should be taken as one unit.

2) After measuring the width of the wall estimate the allowable stress of the masonry. Then using the graphs provided in the Appendix C estimate the allowable UDL on the wall.

3) Now calculate the existing load on the wall. This load will be the sum of load from slab above and wall above this wall. If the existing load is more than the allowable load immediate steps should be taken to reduce load on upper stories. Also check capacity of all the walls below such walls.

Load Estimation on the Floor

The most important aspect of the vulnerability is the estimation of loads, as close to the actual as possible. If the load estimation is not very accurate it will be difficult to rely on the results. The estimation of load highly relies on the training and experience of the inspection engineer. So it is very important that an experienced and trained technical person is deputed for this Evaluation condition.

The following material density should be used for the calculation of dead weight of slabs, beams, columns and wall.

Table1: Material Density

S. No.	Material	Density (kg/m^3)	Note
1	Masonry	1920	As per IS : 875 (Part 1) – 1987
2	Timber	640	Teak wood density as per IS : 875 (Part 1) – 1987
3	Steel	7700	Use per meter weight of section to calculate weight of any section
4	Reinforced concrete	2400	As per IS : 875 (Part 1) – 1987
5	Stone (Ladi)	2800	Stone density of slate as per IS : 875 (Part 1) – 1987

Floor loads should be calculated as per following table based on IS: 875 (Part-2) 1987.

Table 2: Floor Loads forVarious Occupancy Conditions

S. No.	Occupancy description	Floor load (kN/m^2)
1	Residential buildings (all rooms, kitchens, toilet and bathrooms)	2.0
2	Residential buildings (Corridors, passages, staircases, store rooms and balconies)	3.0
3	Hotel kitchen and laundries	3.0
4	Hotel and commercial store rooms	5.0
5	Office rooms	2.5
6	Office store room	4.0

7	Heavy machinery	5.0
8	Vaults and strong room – to be calculated but not less than	5.0
9	Stationary stores	4.0 for each meter of storage height
10	Retail shop	4.0
11	Wholesale shop – to be calculated but not less than	6.0

Calculations and Results

The loads are estimated on each floor as discussed in the previous chapter and are transferred to the supporting slabs, beams, columns and walls. The force in each member is compared with its capacity. The capacity of the member is called Effective Permissible Load which is product of Deterioration Factor (k) and Undamaged Permissible Load. The Deterioration Factor (k) is based on the member damage category as shown in the table below:

Member Damage Category	k (Deterioration factor)
S5 – Unstable	0.0 to 0.4 as per judgment
S5 – Stable	0.5
S4	0.6
S3	0.8
S0-S2	1.0

For the purpose of calculations, following letter symbols shall have the meaning indicated against each:

A = Area of cross section

b = Width of beam/column section

DL = Dead Load, self weight of structural elements

d = Depth of beam/column section

F_c = Masonry strength

F_{ca} = Net allowable compressive stress of masonry

f_{ck} = Characteristic cube compressive stress of concrete

f_y = Characteristic strength of steel

H = Horizontal reaction per meter length along the arch

I = Moment of inertia

IL = Imposed Load, weight of people, furniture etc. (as per IS:875)

I_{xx} = Moment of inertia about X axis

K_A = Area factor (=1.0, assuming area > $0.2m^2$)

K_L = Load factor (=1.0, assuming axial load)

K_{SE} = Stress factor (=1.0 for slenderness ration $\leq$ 6.0 and axial load)

K_u = Factor for shape of masonry unit (=1.0)

l = Length of beam or jack arch floor

l_x = Shorter side of slab

l_y = Longer side of slab

M = Moment

M_u = Design moment for limit state design

M_x = Short span moment (per unit width)

M_y = Long span moment (per unit width)

P = Axial load on column

p_t = Percentage of steel in beam or column

R = Rise of the jack arch floor

r = ly/lx = ratio of long span and short span of slab

SIDL = Superimposed Dead Load, self weight of finishing such as flooring, plaster etc.

t_{arch} = Thickness of jack arch floor

t_{wall} = Thickness of wall

W = UDL on beam or wall (load per unit length of beam or wall)

w = Floor load (load per unit area)

y = Distance of extreme fiber from the centreline

Z = Modulus of section

α_x, α_y = Moment coefficients

σ = Stress

$\sigma_{allowable}$ = Allowable stress in the steel

$\rho_{concrete}$ = Density of concrete

ρ_{timber} = Density of timber

Calculation for Various Structural Elements

Timber Beam

Philosophy and Assumptions

Timber beams are designed assuming that wood is equally effective in tension and compression. So entire cross-section resists moment in form of tension or compression in fibers, unlike RCC section where only steel bars take tension. Following are the assumptions used during the preparation of charts for timber beam:

Calculations for the timber beam are based on working stress method.

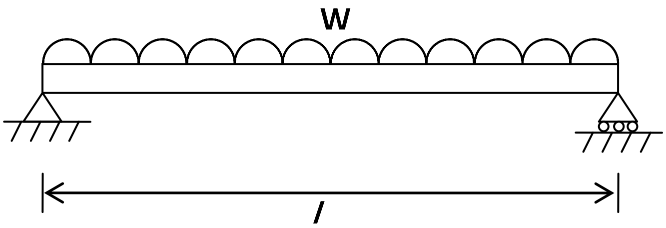
Timber density is assumed as 640 kg/m^3 assuming Teak wood density as per IS: 875 (Part-1)-1987.

Beams are assumed as simply supported so that the mid span moment is maximum, which is being on conservative side.

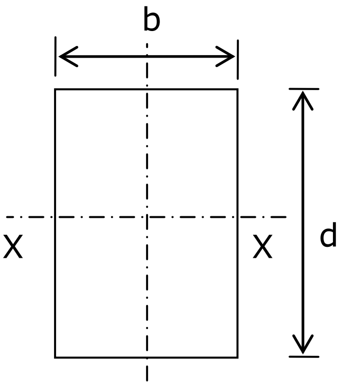
Timber allowable stress is assumed as per IS 883:1994. Charts are prepared for six different values of allowable stresses: 7.5 MPa, 10 MPa, 12.5 MPa, 15 MPa, 20 MPa and 25 MPa.

Formula and Calculations

Assuming a simply supported beam, maximum moment at center will be:



Simply Supported Wooden



Wooden Beam Cross-Section (Moment about X-

$$M = \frac{Wl^2}{8} = Z\sigma_{allowable}$$ ... (1.1)

Where

$$Z = \frac{bd^2}{6}$$ (for rectangular sections) ... (1.2)

$$\frac{Wl^2}{8} = \frac{bd^2}{6}\sigma_{allowable}$$ ... (1.3)

$$W = \frac{4}{3}\frac{bd^2}{l^2}\sigma_{allowable}$$ ... (1.4)

Where W = uniformly distributed dead load and live load on beam or

W = Self weight + SIDL + IL ... (1.5)

Hence, the maximum permissible SIDL+IL,

$$SIDL + IL = \frac{4}{3}\frac{bd^2}{l^2}\sigma_{allowable} - \text{selfweight}$$ ... (1.6)

$$SIDL + IL = \frac{4}{3}\frac{bd^2}{l^2}\sigma_{allowable} - width \times depth \times \rho_{timber}$$ ... (1.7)

Example

Few examples are listed below in the tabular format.

S. No.	b (mm)	d (mm)	Span (m)	Allowable stress (MPa)	Allowable SIDL + IL (kN/m)
1	100	100	2	7.5	2.41
2	100	150	4	7.5	1.28
3	150	100	2	7.5	3.62

4	150	150	4	7.5	1.91
5	150	150	4	10	2.62

Timber Column

Philosophy and Assumptions

Columns carry load in the form of axial load and bending moment along both the directions (major and minor axis). Columns carry load from the beam they support and pass on to the columns of the lower floor. Load carrying capacity of column is governed by two factors: axial load and moment. So the charts are provided in the form of envelope. So if the actual load and moment on the column is lying within the envelope then the column is safe, otherwise not. Following assumptions are made during the preparation of charts for timber column:

Calculations for the timber column are based on working stress method.

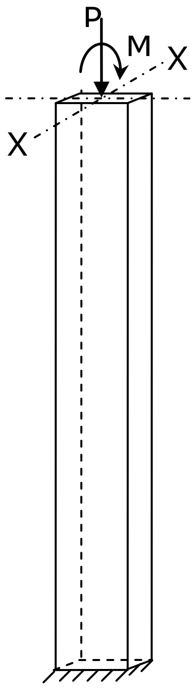
Charts are valid for uni-axial bending case with bending along the major axis.

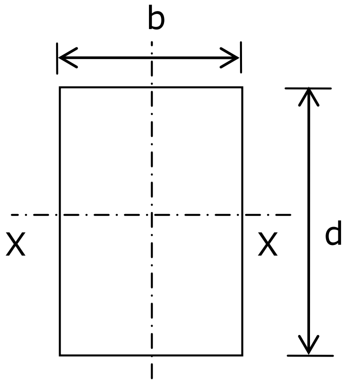
Timber stress-strain curve is assumed to be similar in tension and compression.

Charts are prepared for column sizes 5″x5″ (125x125mm), 6″x6″ (150x150mm), 7″x7″ (175x175mm), 8″x8″ (200x200mm), 10″x10″ (250x250mm) and 12″x12″ (300x300mm) and allowable stresses of 5MPa, 10MPa &15MPa.

Formula and Calculations

Compression (or tension) for uni-axial bending in the extreme fiber of the wooden column can be calculated using the formula:





Wooden Column Cross-Section (Moment about X-

$$\sigma = \frac{P}{bd} + \frac{My}{I} \quad \text{… (2.1)}$$

Where:

P = Axial load on column

b, d = dimension of column

M = Moment on column

y = d/2 = distance of extreme fiber from the centreline

I = $bd^3/12$ = Moment of inertia for rectangular c/s

$$\sigma = \frac{P}{bd} + M\frac{d}{2}\frac{12}{bd^3} \quad \text{… (2.2)}$$

$$\sigma = \frac{P}{bd} + \frac{6M}{bd^2} \le \sigma_{alowable} \quad \text{… (2.3)}$$

Example

Few examples are listed below in the tabular format.

S. No.	b (mm)	d (mm)	Allowable stress (MPa)	Axial load (kN)	Moment (kN-m) (About major axis)
1	125	125	5	50	0.58
2	150	150	10	125	2.5
3	175	175	10	200	3.1
4	200	200	5	100	3.33
5	300	300	15	300	52.5

Jack Arch Floor

Philosophy and Assumptions

Jack arch floors are made of masonry units and their strength is governed by the compressive stress of masonry. Load on the floor is transferred to the beams and girders as uniformly distributed load (UDL) and masonry units of slab are under compression because of its peculiar arrangement. Following are the assumptions made during the preparation of charts for jack arch slab:

Calculations for the jack arch floor are based on working stress method

Charts are valid for the floor where there is no substantial concentrated load on the floor. Any concentrated load may change the stress distribution on the floor, leading towards different mode of failure as against assumed mode of crushing of masonry at the support of jack arch floor.

Calculations are valid for R/l ratio between 1/8 and 1/12.

Calculations are done assuming a rise by span ratio (R/l) as 1/12.

Graphs are prepared for two thickness values of the floor: 115 and 230 mm.

Formulae and Calculations

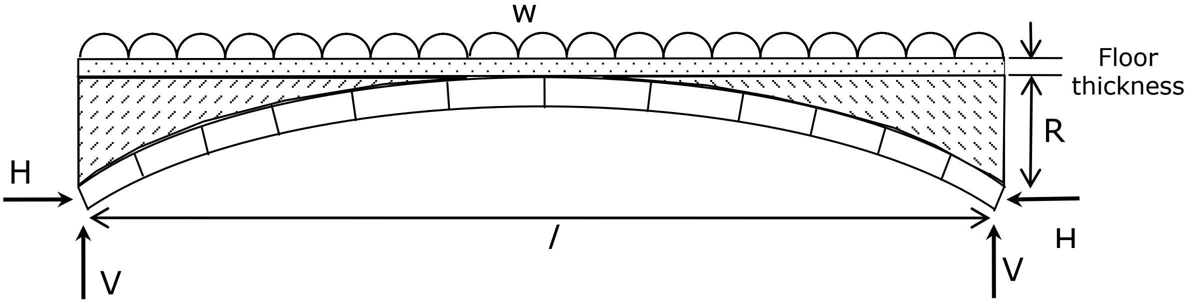
Horizontal reaction (per unit length) at support of jack arch can be expressed approximately as

$$H = \frac{Wl}{8R} \qquad \text{… (3.1)}$$

Where:

H = Horizontal reaction per meter length along the arch

l = Span of the arch



W = Load per meter length along the arch

$$W = wl \qquad \text{… (3.2)}$$

Where:

w = Self weight + SIDL + IL

From eq. 3.3.1 and 3.3.2

$$H = \frac{(wl)l}{8R} \qquad \text{… (3.3)}$$

$$H = \frac{wl^2}{8R} \qquad \text{… (3.4)}$$

$$\text{Selfweight} + SIDL + IL = H\left(\frac{8}{l}\right)\left(\frac{R}{l}\right) \qquad \text{... (3.5)}$$

For crushing of masonry in the floor, the horizontal force should be equal to

$$H = F_{ca} \times 1.0 \times t_{arch} \qquad \text{... (3.6)}$$

Where

F_{ca} = Net allowable compressive stress of masonry; and

t_{arch} = Thickness of jack arch floor

Hence from eq. 3.3.5 and 3.3.6

$$\text{Selfweight} + SIDL + IL = F_{ca} \times t_{arch} \times \left(\frac{8}{l}\right) \times \left(\frac{R}{l}\right) \qquad \text{... (3.7)}$$

Example

Few examples are listed below in the tabular format.

S. No.	L (ft.)	L (m)	F_{ca}(MPa)	t_{arch}(mm)	Self weight + SIDL + IL (kN/m^2) (=$F_{ca}t_{arch}$(8/l)(R/l))
1	3	0.9144	0.25	115	20.96
2	6	1.8288	0.7	115	29.35
3	10	3.048	1.0	115	25.15
4	4	1.2192	0.5	230	62.88
5	8	2.4384	0.6	230	37.73

Masonry Wall

Philosophy and Assumptions

Masonry walls are designed to carry vertical load and local thickening, which is known as pilasters, is provided for lateral load resistance. Following assumptions are made to draw the charts for the masonry walls:

Calculations for the masonry wall are based on working stress method.

It is assumed that only axial load is applied on the walls as the stresses due to moments are negligible compared to axial stress.

Formulae and Calculations

Net permissible compressive stress on masonry wall is calculated as per following formula (IS-1905:1987 clause 5.4.1):

$$F_{ca} = F_c \times K_A \times K_u \times K_L \times K_{SE} \qquad \text{... (4.1)}$$

Where:

F_{ca}: Net allowable compressive strength of masonry

F_c: Masonry strength

K_A: Area factor (=1.0, assuming area > 0.2m^2)

K_u: Factor for shape of masonry unit (=1.0)

K_L: Load factor (=1.0, assuming axial load)

K_{SE}: Stress factor (=1.0 for slenderness ration $\leq$ 6.0 and axial load)

Hence total allowable load on wall is:

$$\text{Total Load} = F_{ca} \times \text{Net Area} \qquad \text{... (4.2)}$$

$$\text{Total Load} = F_c \times K_{SE} \times l \times t_{wall} \qquad \text{...(4.3)}$$

Or allowable UDL on wall:

$$\text{Allowable UDL} = \frac{\text{Total Load}}{l} = F_c \times K_{SE} \times t_{wall} \quad \text{... (4.4)}$$

Example

Few examples are listed below in the tabular format.

S. No.	Wall thickness (m)	Masonry Strength (MPa)	Allowable UDL (kN/m)
1	0.2	1.0	200
2	0.2	1.5	300
3	0.6	2.0	1200
4	0.8	2.0	1600
5	1.0	2.5	2500

RCC Slab (One-way)

Philosophy and Assumptions

A slab is called one-way slab if its longer side (l_y) is more than two times its shorter side (l_x). One way slabs are designed similar to a beam with unit width (b = 1.0m) and moment is transferred to the edge of long span. Load is resisted through moment and shear in the slab. Tension is carried by reinforcement bars and compression by concrete. Shear stirrups are provided to resist shear force, which is maximum at support. Following assumptions are made during the preparation of charts for one-way slab:

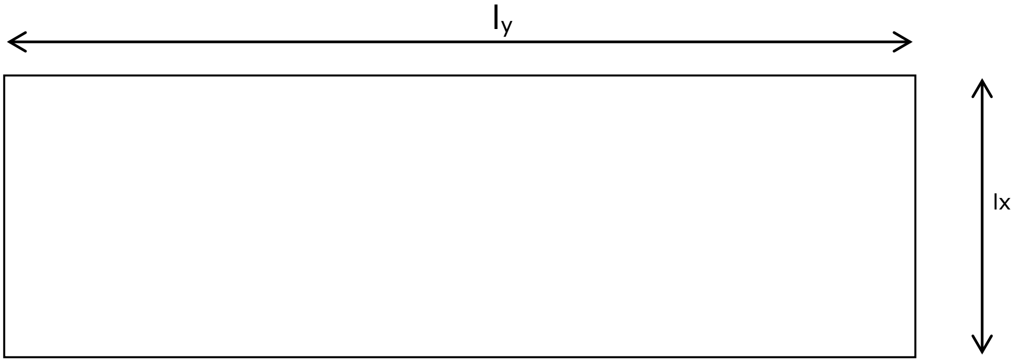
1. Calculations for design of one-way slabs are based on limit state method.

2. Minimum reinforcement of 0.12% (as per IS code) and 0.2% is assumed in the slab for calculation and preparation of the chart.
3. One-way slabs are designed as unit width beam, so b=1000mm.
4. Two different charts are prepared for steel grades of 250MPa and 415MPa.
5. Charts are valid for concrete grade from M10 to M40.
6. Concrete cover of 25mm is assumed in the calculations.

Formulae and Calculations

For a one-way slab

$$\frac{l_y}{l_x}(=r) > 2.0 \quad \text{... (5.1)}$$



RCC one-way slabs are designed as beams, assuming unit width. Following formula is used to design RCC beams (SP 16:1980, clause: 2.3.1):

$$\frac{M_u}{bd^2} = 0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \quad \text{... (5.2)}$$

Assuming simply supported slab, maximum mid-span moment will be:

$$M_u = \frac{Wl^2}{8} \quad \text{... (5.3)}$$

Where W = weight per unit width of slab = w x 1.0

w = DL + IL = load per unit area

Hence,

$$w = DL + LL = \frac{8bd^2}{l^2} 0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \quad \text{... (5.4)}$$

but DL = Self Weight + SIDL

Hence allowable SIDL + IL on the slab, assuming factor of safety as 1.5, is:

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l^2} 0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - \text{selfweight} \quad \text{... (5.5)}$$

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l^2} 0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - b \times d \times \rho_{concrete} \quad \text{... (5.6)}$$

Example

Few examples are listed below in the tabular format.

S. No.	Short span (m)	Depth (mm)	f_y (MPa)	f_{ck} (MPa)	Allowable load (SIDL + IL) (kN/m^2)
1	2	100	230	10	0.36
2	2	120	230	10	1.59
3	2	150	230	10	4.20
4	2	200	230	10	10.59
5	3	200	230	10	1.93

RCC Slab (Two-way)

Philosophy and Assumptions

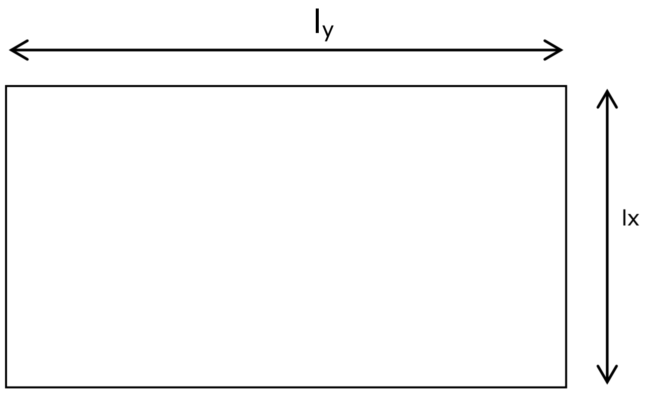
A slab is called is called two-way slab if its longer side (l_y) is less than or equal to two times its shorter side (l_x). In the design of two way slab moments are distributed to the support as per Rankine-Grashoff Theory. Unlike one-way slab moment is transferred to all the four supports in a two-way slab depending on l_y/l_x ratio. Load is resisted through moment and shear in the slab. Tension is carried by reinforcement bars and compression by concrete. Shear stirrups are provided to resist shear force, which is maximum at support. Following assumptions are made during the preparation of charts for two-way slab:

1. Calculations for design of two-way slabs are based on limit state method.
2. Minimum reinforcement of 0.12% (as per IS code) and 0.2% is assumed in the slab for calculation and preparation of the chart.
3. Two-way slabs charts are prepared for l_y/l_x ratio of 1.0.
4. Two different charts are prepared for steel grades of 230MPa and 415MPa.
5. Charts are valid for concrete grade from M10 to M40.
6. Concrete cover of 25mm is assumed in the calculations.

Formulae and Calculations

For a two-way slab

$$1.0 \le \frac{l_y}{l_x}(=r) \le 2.0 \qquad \text{… (6.1)}$$



As per Rankine-Grashoff Theory

$M_x = \alpha_x w l_x^2$ ... (6.2)

and $M_y = \alpha_y w l_y^2$ ... (6.3)

Where:

$$\alpha_x = \frac{1}{8}\left[\frac{r^4}{1+r^4}\right] \quad \text{... (6.4)}$$

$$\alpha_y = \frac{1}{8}\left[\frac{r^2}{1+r^4}\right] \quad \text{... (6.5)}$$

$$r = \frac{l_y}{l_x} \quad \text{... (6.6)}$$

Beam design formula is applicable here also;

$$\frac{M_x}{bd^2} = \frac{\alpha_x w l_x{}^2}{bd^2} = 0.87 f_y\left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \quad \text{... (6.7)}$$

$$w = \frac{bd^2}{\alpha_x l_x{}^2} 0.87 f_y\left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \quad \text{... (6.8)}$$

$$w = \frac{bd^2}{\frac{1}{8}\frac{r^4}{1+r^4} l_x{}^2} 0.87 f_y\left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \quad \text{... (6.9)}$$

$$w = \frac{8bd^2}{l_x^2}\frac{(1+r^4)}{r^4}0.87 f_y\left(\frac{p_t}{100}\right)\left[1-\frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \qquad \text{... (6.10)}$$

$$DL + IL = \frac{8bd^2}{l_x^2}\left(1+\frac{1}{r^4}\right)0.87 f_y\left(\frac{p_t}{100}\right)\left[1-\frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right] \qquad \text{... (6.11)}$$

but DL = Self Weight + SIDL

Hence allowable SIDL + IL on the slab, assuming factor of safety as 1.5

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l_x^2}\left(1+\frac{1}{r^4}\right)0.87 f_y\left(\frac{p_t}{100}\right)\left[1-\frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - \text{selfweight} \qquad \text{... (6.12)}$$

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l_x^2}\left(1+\frac{1}{r^4}\right)0.87 f_y\left(\frac{p_t}{100}\right)\left[1-\frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - b \times d \times \rho_{concrete} \qquad \text{... (6.13)}$$

Example

Few examples are listed below in the tabular format.

S. No.	Short span (m)	Depth (mm)	f_y (MPa)	f_{ck} (MPa)	Allowable load (SIDL + IL) (kN/m^2)
1	2	100	230	10	3.23
2	2	120	230	10	6.19
3	2	150	230	10	12.16
4	2	200	230	10	26.18
5	3	200	230	10	8.86

RCC Beam

Philosophy and Assumptions

RCC beam carries load from wall and slab and transfers it to column. Tension is resisted by the reinforcement at the bottom of the beam and compression by concrete at the top. Following assumptions are made for the preparation of the charts of RCC beam:

1. Design calculations are based on limit state method.
2. Minimum reinforcement of 0.2% (as per code) and additionally 0.3% and 0.4% reinforcement is assumed in the beam for calculation and preparation of the chart.
3. Two different charts are prepared for steel grades of 250MPa and 415MPa.
4. Charts are valid for concrete grade of M10 to M40.
5. Concrete cover of 40mm is assumed in the calculations.

Formula and Calculations

RCC beam is designed as per following formula, using limit state method:

$$\frac{M_u}{bd^2} = 0.87 f_y \left(\frac{p_t}{100} \right) \left[1 - \frac{f_y}{f_{ck}} \left(\frac{p_t}{100} \right) \right] \qquad \text{... (7.1)}$$

Assuming simply supported beam, maximum mid-span moment will be:

$$M_u = \frac{Wl^2}{8} \qquad \text{... (7.2)}$$

Where W = uniformly distributed dead load and live load on beam or

W = Self weight + SIDL + IL

Hence,

$$W = \frac{8bd^2}{l^2} 0.87 f_y \left(\frac{p_t}{100} \right) \left[1 - \frac{f_y}{f_{ck}} \left(\frac{p_t}{100} \right) \right] \qquad \text{... (7.3)}$$

Hence allowable SIDL + IL on the slab, assuming factor of safety as 1.5, is:

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l^2}0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - \text{selfweight} \quad \text{... (7.4)}$$

$$SIDL + IL = \frac{1}{1.5}\left[\frac{8bd^2}{l^2}0.87 f_y \left(\frac{p_t}{100}\right)\left[1 - \frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]\right] - b \times d \times \rho_{concrete} \quad \text{... (7.5)}$$

Example

Few examples are listed below in the tabular format.

S. No.	Beam span (m)	Depth (mm)	f_y (MPa)	f_{ck} (MPa)	Allowable load (SIDL + IL) (kN/m)
1	2	250	230	10	3.73
2	2	300	230	10	6.19
3	2	350	230	10	9.24
4	3	250	230	10	0.86
5	3	300	230	10	1.79

RCC Column

Philosophy and Assumptions

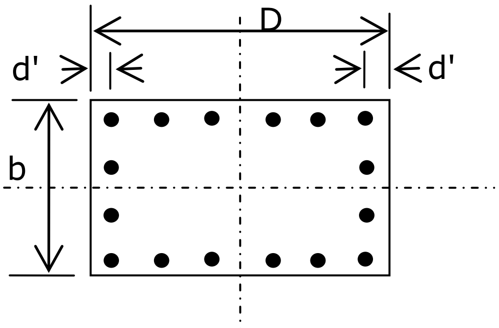
RCC columns are designed to carry axial load as well as moment. Allowable moment for a given load or allowable load for a given moment can be decided using the P-M curves. Such curves are developed for the uni-axial bending case, with bending along major axis. Calculations are done using limit state method. These curves are developed using MATLAB programme. Following assumptions were made for the calculation of P-M curve for columns:

1. All calculations are done using limit state method.
2. Minimum reinforcement of 0.8% (as per IS code) and additionally 1.0% and 1.2% reinforcement is assumed in the column for calculation and preparation of chart.
3. These charts are not valid for slander columns.
4. Clear cover is assumed as 0.1D.
5. Two different charts are prepared for steel grades of 250MPa and 415MPa.
6. Charts are given for concrete grade M10, M15 and M20.

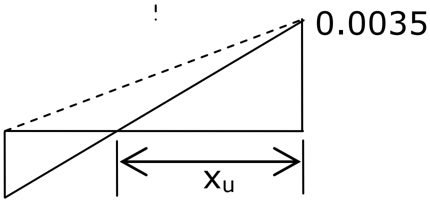
Formula and Calculations

RCC column is made of two different materials: concrete and reinforcement steel. These two materials are significantly different in behaving under compression and tension. Basic assumption around which the calculations are based is that the strain is same in steel and concrete at their contact point. So the two materials do not slip with respect to each other under the application of load. Stress-strain relationship for concrete and steel is assumed as given in SP 16: 1980. P-M curve for any given cross section is calculated as follows:

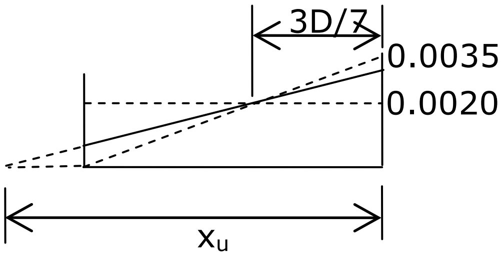
1. Axial load capacity of the column is calculated for the given dimension and percentage of reinforcement. This value is P_u. Allowable compressive strain for this case is 0.002.
2. Moment capacity of the column is calculated such that the extreme fiber compressive strain for concrete is 0.0035. This value is M_u. Calculate corresponding location of neutral axis (x_u).
3. Now increase the value of x_u gradually and for each step and calculate axial force and moment on the cross-section.
4. Plot this result on graph by plotting axial load on the Y-axis and moment on X-axis. This curve is called P-M curve. Any (M, P) coordinate situated under this curve indicates the safe column.



Column cross section



Strain diagram for Natural axis inside the section



Strain diagram for Natural axis outside the section

Example

Few examples are listed below in the tabular format.

S. No.	Column width (D) (mm)	Column thickness (b) (mm)	f_y (MPa)	f_{ck} (MPa)	P_u(kN)	M_u(kN-m)	P_u / $f_{ck}bD$	M_u / $f_{ck}bD^2$	Safe/Unsafe (using graph)
1	300	230	230	10	100	20	0.145	0.097	Unsafe
2	300	300	230	10	150	15	0.167	0.056	Safe
3	400	300	230	10	300	30	0.25	0.063	Safe
4	500	300	230	10	500	50	0.333	0.067	Unsafe
5	600	450	230	10	500	50	0.185	0.031	Safe

Steel Beam

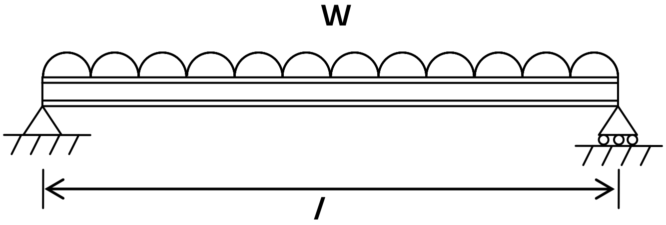
Philosophy and Assumptions

Steel beams are designed with the same concept as wooden beam. Entire cross section is assumed to be effective, i.e. resisting moment through tension and compression. It supports wall and slab and transfers load to column or wall. Following assumptions are made while preparing the charts for steel beam:

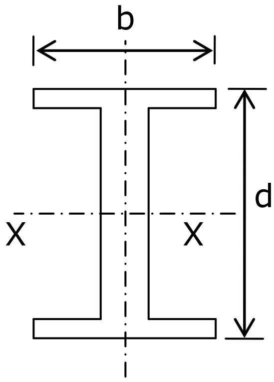
1. Calculations are based on working stress method.
2. Allowable stress in steel is $0.66f_y$. Steel grade is considered as 250MPa.
3. Charts are prepared for various ISMB sections specified in Steel Table
4. Beams are assumed as simply supported for calculation.

Formula and Calculations

Mid-span moment for a simply supported steel beam is:



Simply Supported Steel Beam



Steel Beam Cross-Section (Moment

$$M = \frac{Wl^2}{8} = \frac{I}{y}\sigma_{allowable} \qquad \text{… (9.1)}$$

$$W = \frac{8}{l^2}\frac{I}{y}\sigma_{allowable} \qquad \text{… (9.2)}$$

Where:

I = Moment of inertia of cross section

y = Distance of extreme fiber from the centreline

W = Uniformly distributed load on beam or wall

w = Self weight + SIDL + IL

$$SIDL + IL = \frac{8}{l^2}\frac{I}{y}\sigma_{allowable} - \text{selfweight} \qquad \text{... (9.3)}$$

Example

Few examples are listed below in the tabular format.

S. No.	Steel Section	Span (m)	Allowable SIDL + IL (kN/m)
1	ISMB100	4	4.13
2	ISMB150	6	3.4
3	ISMB 300	3	83.69
4	ISMB 350	8	15.54
5	ISMB 400	8	20.48

Steel Column

Philosophy and Assumptions

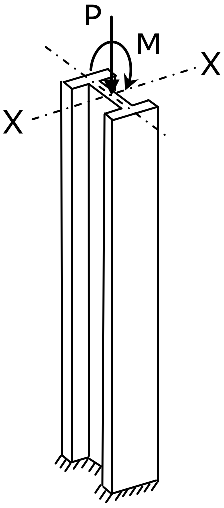
Following assumptions are made during the preparation of charts for steel column.

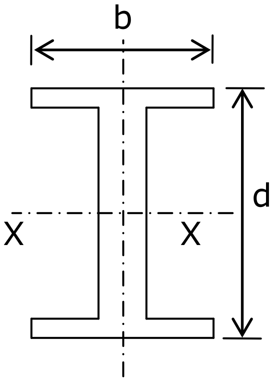
1. Calculations for steel column are based on working stress method.
2. Allowable stress in steel is $0.66f_y$. Steel grade is considered as 250MPa.

3. A uniform slenderness ratio of 40 is assumed for all the columns. For this reason the allowable stress for steel columns is 139 MPa as per IS: 800 – 1984.
4. Charts are valid for uni-axial bending case with bending along the major axis.

Formula and Calculations

Similar to timber column, compression (or tension) for uni-axial bending in the extreme fiber of the column can be calculated using the formula.





Steel Column Cross-Section (Moment about

$$\sigma = \frac{P}{A} + \frac{My}{I} \qquad \text{... (10.1)}$$

$$\sigma = \frac{P}{A} + \frac{M}{I_{xx}}\frac{d}{2} \le \sigma_{allowable} \qquad \text{... (10.2)}$$

Where:

A = cross section area of the column

I_{xx} = Moment of inertia about the X-axis

Example

Few examples are listed below in the tabular format.

S. No.	Column type	Axial load (kN)	Moment along major axis (kN-m)
1	ISMB125	100	5.66
2	ISMB150	250	0.72
3	ISMB200	250	4.76
4	ISMB300	200	59.34
5	ISMB350	800	14

Appendix A

Data Collection Form

The data collection forms for Rapid Visual Screening of Buildings for Seismic Vulnerability and Condition Assessment are:

RAPID VISUAL SCREENING OF BUILDINGS FOR POTENTIAL SEISMIC VULNERABILITY AND CONDITION ASSESSMENT

Sheet A

PHOTOGRAPH Nos.

Survey Engineer Details:

Name:______________________________
Contact Number:______________________
e-mail:_____________________________

Building Details:

Address:____________________________________
____
Village/Town/City_______________District_______________State_________________PIN_______________
Landmark:___________________________________
GPS Coordinates:_____________________________
No. Stories:______________ Year Built:_____________
Date:_______________________________________
Total Floor Area (sq. m):_______________________
Building Name:______________________________
Use:____
Construction Drawings Available: ☐Yes/☐No

OCCUPANCY TYPE

Assembly	Govt.	Office
Commercial	Historic	Residential
Emer. Service	Industrial	School

OCCUPANCY LOAD

Max. Number of Persons

0-10	11-100
101-1000	1000+

SOIL TYPE (IS 1893:2002)

TYPE I	**TYPE II**	**TYPE III**
Hard Soil	Medium Soil	Soft Soil

FALLING HAZARDS

☐	☐	☐	☐
Chimneys	Parapets	Cladding	Other:

SITE MORPHOLOGY

☐	☐	☐	☐	☐	☐
Flat	Crest	Embankment	Downward Slope	Trough	Adjacent to Hill Slopes

Slope of the Terrain (Degrees) ____________

ASSESSMENT

Investigate the building for the conditions given below and check the appropriate column

IBroad Structural Observations:

Any storey/building noticeably leaning	☐Yes	☐No	
Estimated maximum floor loading (SIDL+IL)	☐Normal	☐Excessive	

II Geotechnical/Foundation Observations:

Subsidence, unequal settlements	☐Yes	☐No	☐Not Known
Plinth level lowered	☐Yes	☐No	☐Not Known

III Condition of Vertical Structural Elements

(Fill separately for each floors using enclosed forms A.1)

IV Condition of Horizontal Structural Elements

(Fill separately for each floors using enclosed forms A.2)

V Capacity of Vertical Structural Elements

(Fill separately for each floors using enclosed forms A.3)

VI Capacity of Horizontal Structural Elements

(Fill separately for each floors using enclosed forms A.4)

A.1

III Condition of Vertical Structural Elements (*One Form/Floor*)

Floor No:__________

WALL:

Load Bearing Wall: ☐ Yes ☐No

If Yes,Total no. of beams: ___Nos. inspected ___Nos. un-inspected

Wall thickness(mm) ☐230 ☐350☐450☐600☐Other_______

Type of mortar ☐Mud☐Lime☐Cement☐Gauged

Is masonry reinforced? ☐ Yes ☐No

No. of walls having diagonal/cross cracks S0-S1____ S2-S3____ S4____ S5____

No. of walls having vertical cracks (Except corners) S0-S1____ S2-S3____ S4____ S5____

Bulging or out of plane failure S0-S1____ S2-S3____ S4____ S5____

Separation of walls (vertical cracks at corner/T-junction) ☐ Yes ☐No

If Yes, at corners (Number of walls) S0-S1____ S2-S3____ S4____ S5____

at T - Junctions (Number of walls) S0-S1____ S2-S3____ S4____ S5____

Openings bridged by using: ☐RC Lintels ☐Masonry Arches ☐ Flat Brick Lintels ☐Timber Lintels☐None

Openings

Nos. with inclined/toothing cracks originating from corners S0-S1____ S2-S3____ S4____ S5____

Nos. with cross cracks in piers between openings S0-S1____ S2-S3____ S4____ S5____

Arches:

Cracks in arches: ☐ Yes ☐No

Arches collapsed ☐ Yes ☐No

Partition Wall: ☐ Yes ☐No

If Yes,Total no. of partition walls inspected ___Nos.

Estimated no. of non-inspected partition walls: ___Nos.

Number of Partition walls that have:

Diagonal/cross cracks ___No. of Walls

Vertical cracks ___No. of Walls

Separation from main wall / column ___No. of Walls

Bulging or out of plane failure ___No. of Walls

Horizontal cracks:

at Sill Level ___No. of Walls

at Lintel Level ___No. of Walls

at Floor Level ___No. of Walls

COLUMNS:

Total no. of Columns: ___Nos. inspected ___Nos. un-inspected

Timber (Wooden) Columns: ☐ Yes ☐No

If Yes, total no. of columns (inspected): ___Nos.

Diagonal cracks /cross cracks S0-S1____ S2-S3____ S4____ S5____

Significant reduction in cross section S0-S1____ S2-S3____ S4____ S5____

Crushing or decay of timber S0-S1____ S2-S3____ S4____ S5____

RCC Columns: ☐ Yes ☐No

If Yes, total no. of columns (inspected): ___Nos.

Cracks at beam-column junction S0-S1____ S2-S3____ S4____ S5____

Diagonal cracks /cross cracks S0-S1____ S2-S3____ S4____ S5____

Spalling of concrete S0-S1____ S2-S3____ S4____ S5____

Crushing of concrete or/and buckling of bars S0-S1____ S2-S3____ S4____ S5____

Steel Columns: ☐ Yes ☐No

If Yes, total no. of columns (inspected): ___Nos.

Knee bracing provided? S0-S1____ S2-S3____ S4____ S5____

Buckling or bowing of columns? S0-S1____ S2-S3____ S4____ S5____

Tilting or inclination of columns? S0-S1____ S2-S3____ S4____ S5____

Rusting of columns? S0-S1____ S2-S3____ S4____ S5____

Condition of welds/rivets/bolts at joints S0-S1____ S2-S3____ S4____ S5____

A.2

IV Condition of Horizontal Structural Elements (One Form/Suspended Slab) **Suspended Slab No:__________**

Total no. of beams: ___Nos. inspected ___Nos. un-inspected

Timber (Wooden) Beam: ☐ Yes ☐No ☐ Not Known
If Yes, no. of framing beams (inspected) ___Nos.
Nos. with loss of support/displacement of beam S0-S1____ S2-S3____ S4____ S5____
Nos. with weathering/disintegration of beam near support S0-S1____ S2-S3____ S4____ S5____
Nos. with noticeable deflection/sagging S0-S1____ S2-S3____ S4____ S5____
Are chords present? ☐ Yes ☐No ☐ Not Known
If Yes, nos. of chords have been bent in lateral direction? S0-S1____ S2-S3____ S4____ S5____

Concrete Beam: ☐ Yes ☐No ☐ Not Known
If Yes, no. of framing beams (inspected) ___Nos.
No. of beams with horizontal tension cracks at bottom S0-S1____ S2-S3____ S4____ S5____
No. of beams with vertical cracks near supports S0-S1____ S2-S3____ S4____ S5____
No. of beams with vertical cracks near mid-span S0-S1____ S2-S3____ S4____ S5____
No. of beams with diagonal cracks near supports S0-S1____ S2-S3____ S4____ S5____
Nos. with noticeable deflection/sagging S0-S1____ S2-S3____ S4____ S5____

Steel Beam: ☐ Yes ☐No ☐ Not Known
If Yes, no. of framing beams (inspected) ___Nos.
If Yes, no. with noticeable deflection/sagging S0-S1____ S2-S3____ S4____ S5____
Weathering/corrosion of beam S0-S1____ S2-S3____ S4____ S5____
Condition of welds/rivets/bolts at joints S0-S1____ S2-S3____ S4____ S5____
Loss of support / displacement of beams S0-S1____ S2-S3____ S4____ S5____
Floor beams have been braced horizontally? ☐ Yes ☐No ☐ Not Known
If Yes, connection between bracings & beams damaged? S0-S1____ S2-S3____
Diagonals of bracing have buckled or yielded? S0-S1____ S2-S3____
Chords have been bent in lateral direction? S0-S1____ S2-S3____

RCC Slab: ☐ Yes ☐No ☐ Not Known
If Yes, spalling of concrete/exposed reinforcement S0-S1____ S2-S3____ S4____ S5____
Excessive deflection of slab S0-S1____ S2-S3____ S4____ S5____
Cantilever slabs are damaged? S0-S1____ S2-S3____ S4____ S5____
Punching shear damage? S0-S1____ S2-S3____ S4____ S5____
Are there cut-outs in slabs? ☐ Yes ☐No ☐ Not Known
If Yes, then indicate damage adjacent to cut-out ☐ None/Minor ☐Moderate ☐ Severe
Corner cracks next to cut-out ☐ None/Minor ☐Moderate ☐ Severe

Floor Supported on Timber (Wooden) Joists: ☐ Yes ☐No ☐ Not Known
If Yes, excessive deflection of slab S0-S1____ S2-S3____ S4____ S5____
Nos. of Joists ___Nos. failed ___Nos. excessively bent
___Nos. moved from supporting wall/binder

Floor Supported on Steel Joists: ☐ Yes ☐No ☐ Not Known
If Yes, excessive deflection of slab S0-S1____ S2-S3____ S4____ S5____
Loss of section due to rusting of joists ________
Bending (Sagging of Joists) ________

Jack Arch Floor: ☐ Yes ☐No ☐ Not Known
If Yes, joists supporting vault ☐ RCC ☐Steel
Excessive deflection of Joists ________No. of Joists
Failure in vaults ________Nos. cracked ________Nos. cracked
Ties provided ☐ Yes ☐No **If yes,**No. failed ties: ___Nos.

Hollow Block Floor: ☐ Yes ☐No ☐ Not Known
If Yes, spalling of concrete / exposed reinforcement ________
Vertical displacement due to support movement ________
Connections in slab damaged ________

Caststone slab: ☐ Yes ☐No ☐ Not Known
If Yes, spalling of concrete / exposed reinforcement ________
Vertical displacement due to support movement ________
Connections in slab damaged ________

A.3

V Capacity of Vertical Structural Elements (One Form/Floor) Floor No:___________

RCC Columns ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Column Size b (mm)									
Column Size d (mm)									
Rebar percentage (0.8%, 1% or 1.2%)									
Rebar grade (fy=250 or 415)									
Concrete grade (M10, M15 or M20)									
Estimated Load P (kN)									
Estimated Moment M (kN-m)									
Graph Number (used in calculations)									
Are P&M in safe range as per PM curve									
Result (Safe/Unsafe)									

Wooden Columns ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Column Size b (mm)									
Column Size d (mm)									
Estimated Load P (kN)									
Estimated Moment M (kN-m)									
Graph Number (used in calculations)									
Are P&M in safe range as per PM curve									
Result (Safe/Unsafe)									

Steel Columns ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Column Type									
Estimated Load P (kN)									
Estimated Moment M (kN-m)									
Graph Number (used in calculations)									
Are P&M in safe range as per PM curve									
Result (Safe/Unsafe)									

Masonry Wall ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Thickness of wall (m)									
Length of wall (m)									
Estimated Load on wall (kN/m)									
Graph Number (used in calculations)									
Undamaged permissible load (kN/m)									
Effective permissible load (kN/m)									
Result (Safe/Unsafe)									

VI Capacity of Horizontal Structural Elements (One Form/Suspended Slab) Suspended Slab No:___________

A.4

Jack Arch Floor Slab ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Span of Floor (m)									
Characteristic Strength (MPa)									
Arch Thickness (mm)									
Estimated Floor Load (kN/m²)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m²)									
Effective Permissible Load (kN/m²)									
Result (Safe/Unsafe)									

RCC Floor One Way Slab ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Short Span (m)									
Depth (mm)									
Rebar percentage (0.12% or 0.2%)									
Rebar grade (fy=250 or 415)									
Estimated Floor Load (kN/m²)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m²)									
Effective Permissible Load (kN/m²)									
Result (Safe/Unsafe)									

RCC Floor Two Way Slab ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Short Span (m)									
Depth (mm)									
Rebar percentage (0.12% or 0.2%)									
Rebar grade (fy=250 or 415)									
Estimated Floor Load (kN/m²)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m²)									
Effective Permissible Load (kN/m²)									
Result (Safe/Unsafe)									

RCC Beam ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Span of Beam(m)									
Depth of Beam (mm)									
Width of beam (230/300/350mm)									
Rebar percentage (0.2%/0.3%/0.4%)									
Rebar grade (fy=250 or 415)									
Estimated Load on Beam (kN/m)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m)									
Effective Permissible Load (kN/m)									
Result (Safe/Unsafe)									

Wooden Beam or Joist ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Span of Beam(m)									
Depth of Beam (mm)									
Width of Beam (mm)									
Estimated Load on Beam (kN/m)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m)									
Effective Permissible Load (kN/m)									
Result (Safe/Unsafe)									

Steel Beam or Joist ☐ Yes ☐No

Member No. or Designation									
Member Damage Category									
Steel Section Designation									
Span of Beam (m)									
Estimated Load on Beam (kN/m)									
Graph Number (used in calculations)									
Undamaged Permissible Load (kN/m)									
Effective Permissible Load (kN/m)									
Result (Safe/Unsafe)									

VII BUILDING SAFETY LEVEL

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

Floor No. _______________		
Structural Element	**Safe (Nos.)**	**Unsafe (Nos.)**
RCC column		
Wooden Column		
Steel Column		
Masonry Wall		
Jack Arch Floor		
RCC slab (One-Way)		
RCC slab (Two-Way)		
RCC Beam		
Wooden Beam		
Steel Beam		

RESULTS

I Building Damage Safety Level (On the basis of visual condition assessment)

☐ S0 – S2

☐ S3

☐ S4

☐ S5

II Detailed Assessment of the Building (On the basis of calculations)

☐ S0 – S2

☐ S3

☐ S4

☐ S5

III Further Evaluation Recommended

☐ Yes ☐ No

COMMENTS AND REMARKS

Appendix B

Damage Category Assessment Guidelines

Table1: Damage Category Assessment Guidelines for Structural Elements

Damage Category	Building Element			
	Steel Column	**Steel Beam**	**Jack Arch Floor**	**Timber Post**
S5	Excessive inter-storey deflection; Buckling of column; Failure of joints with beams; Failure of connection with foundation; Significant loss of cross-section due to corrosion	Loss of support; Failure of connection with columns; Buckling of web; Significant loss of cross-section due to corrosion	Loss of arch action; Dislodgement of keystone; Failure of tie-member; Partial or full collapse	Significant reduction in cross-section; Failure of connection with beams; Excessive inter-storey drift/tilting; Severe rotting of timber
S4	Moderate loss of cross-section due to corrosion; Twisting of column; Significant distress in bolts and shims; Cracks in welds	Moderate loss of cross-section due to corrosion; Torsional deformation; Differential settlement of supports; Significant distress in bolts and shims; Cracks in welds	Loosening of keystone; Wide cracks (> 2mm) near arch crown	Severe distress in connections and supports; Minor cracks in post; Moderate rotting
S3	Minor loss of cross-section due to	Minor loss of cross-section due to	Moderate cracks (1-2 mm) near	Minor rotting; visibly looking

	corrosion; Minor distress in connections	corrosion; Minor distress in connections	arch crown; Minor reduction in tie-member cross section	safe
S2	--	--	Visible cracks near arch crown; Falling of plaster near arch crown	--
S1	--	--	Visible cracks away from crown; Falling of plaster away from crown	--
S0	No damage	No damage	No damage	No damage

Table 2: Damage Category Assessment Guidelines for Structural Elements

Damage Category	**Building Element**			
	Timber Beam	**RCC Column and Shear Wall**	**RCC Beam**	**Load Bearing Wall**
S5	Significant reduction in cross-section; Failure of connection with column; Crushing of member at any section; Differential support settlement; Severe rotting of timber	Crushing of core concrete at joints, relative movement with respect to slab and other columns	Crushing of concrete at supports, excessive deflection	Partial or total collapse of wall; Wide cracks (> 2mm) in crown of wall arch

S4	Apparent loss of support; Excessive deflection at mid-span; Moderate rotting	Diagonal / Torsional cracks in concrete core (>0.5 mm), opening of tie bars, buckling of longitudinal bars, non-uniform reinforcement size	Reinforcement and concrete bond is broken, cracks in the core concrete (>0.5 mm), shear tie bars have failed	Gaps in the wall, separation at openings (e.g. windows, doors); Moderate cracks (1-2 mm) in crown of wall arch
S3	Minor rotting; visibly looking safe	Major portion of outer layer of concrete is spalled but core is intact except for hairline cracks (<0.5 mm)	Major portion of outer layer of concrete is spalled but core is intact except for hairline cracks (<0.5 mm)	Wide and deep cracks (1 - 2 mm) in wall areas other than crown of wall arch, out of plane movement
S2	--	Visible cracks (up to 0.1-0.2 mm)	Visible shear cracks (near support) or tension cracks (at bottom) (up to 0.1-0.2 mm)	Visible cracks (up to 0.1-0.2 mm), some falling of plaster
S1	--	Very fine cracks (<0.1mm)	Very fine cracks (<0.1mm)	Very fine cracks (<0.1mm)
S0	No damage	No damage	No damage	No damage

Table 3: Building Damage Categorisation Based on Structural Element Categories

Building Category	Description
S0-S2	Highest category member is S0-S2

	Highest category member is S3 and not satisfying condition for S3 building category.
S3	Highest category member is S3 and more then 50% of observed vertical supporting members and/or more then 75% of observed horizontal members **on any floor** are in S3 category.
S4	Highest category member is S5 and not satisfying condition for S5 building category. Highest category member is S4
S5	Some members are in S5 category and building experiences partial collapse, leaning, significant settlement or any other sign of loss of stability of any portion/floor of building.

Table 4: Building Damage Categorization Based on Structural Element Evaluation

Building Category	**Description**
S0-S2	All inspected members are safe.
S3	If any of these conditions are satisfied: a) Beam and slab: up to 20% of inspected members are unsafe. b) Column and wall: up to 10% of inspected members are unsafe. c) Conditions for S4 or S5 are not satisfied.
S4	If any of these conditions are satisfied: a) Beam and slab: 20% to 40% of inspected

	members are unsafe. b) Column and wall: 10% to 20% of inspected members are unsafe. c) Conditions for S5 are not satisfied.
S5	If any of these conditions are satisfied: a) Beam and slab: more than 40% of inspected members are unsafe. b) Column and wall: more than 20% of inspected members are unsafe. c) Partial collapse of building. d) Leaning, significant settlement or any other sign of loss of stability of any portion/floor of building.

Example Damage Categories

Figure 24 Masonry load bearing wall (S1-category)

Figure 25 Masonry load bearing wall (S1-category)

Figure 26 Masonry load bearing wall (S1-category)

Figure 27 Masonry load bearing wall (S1-category)

Figure 28 Masonry load bearing wall (S2-category)

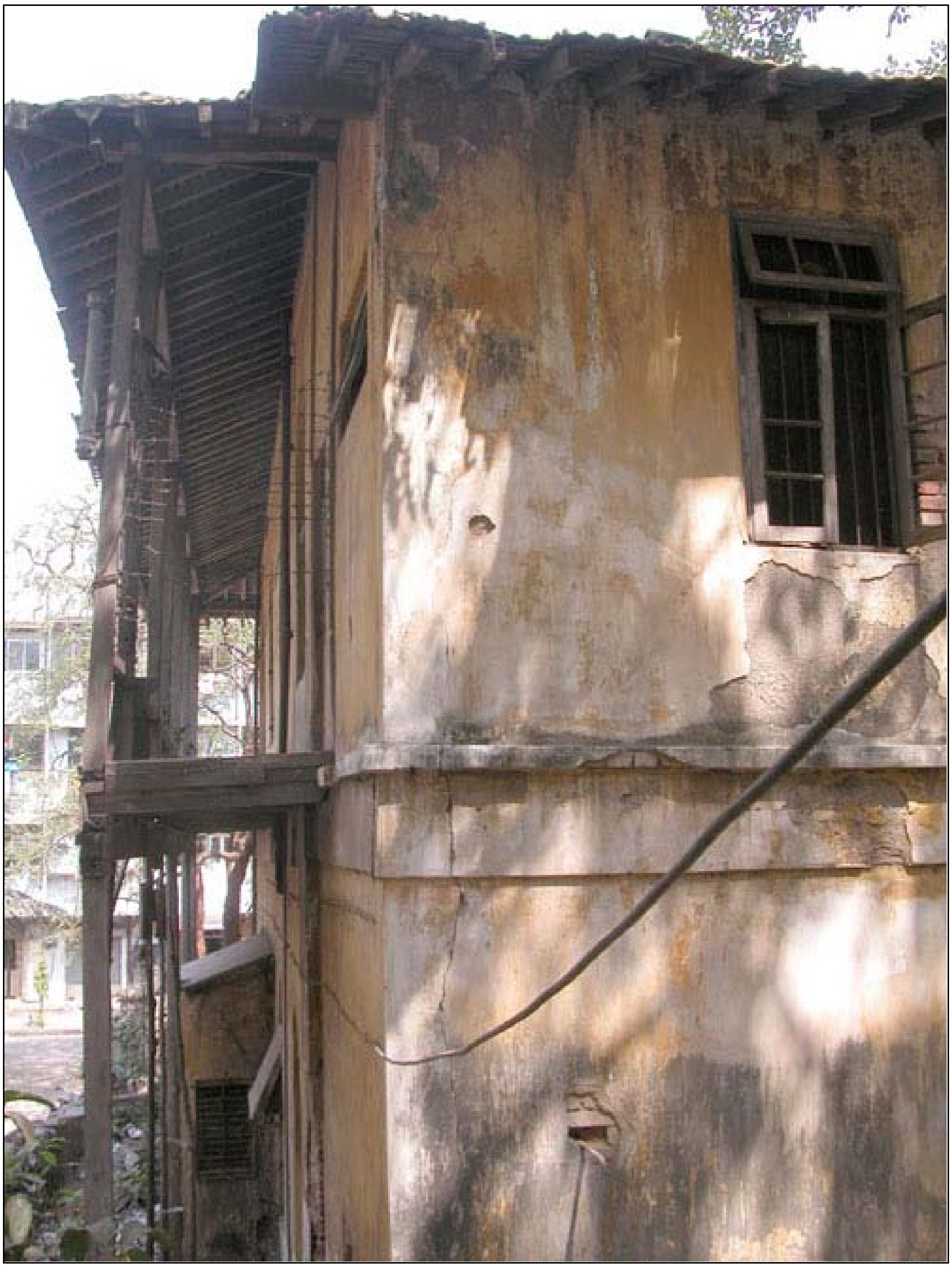


Figure 29 Masonry load bearing wall (S2-category)

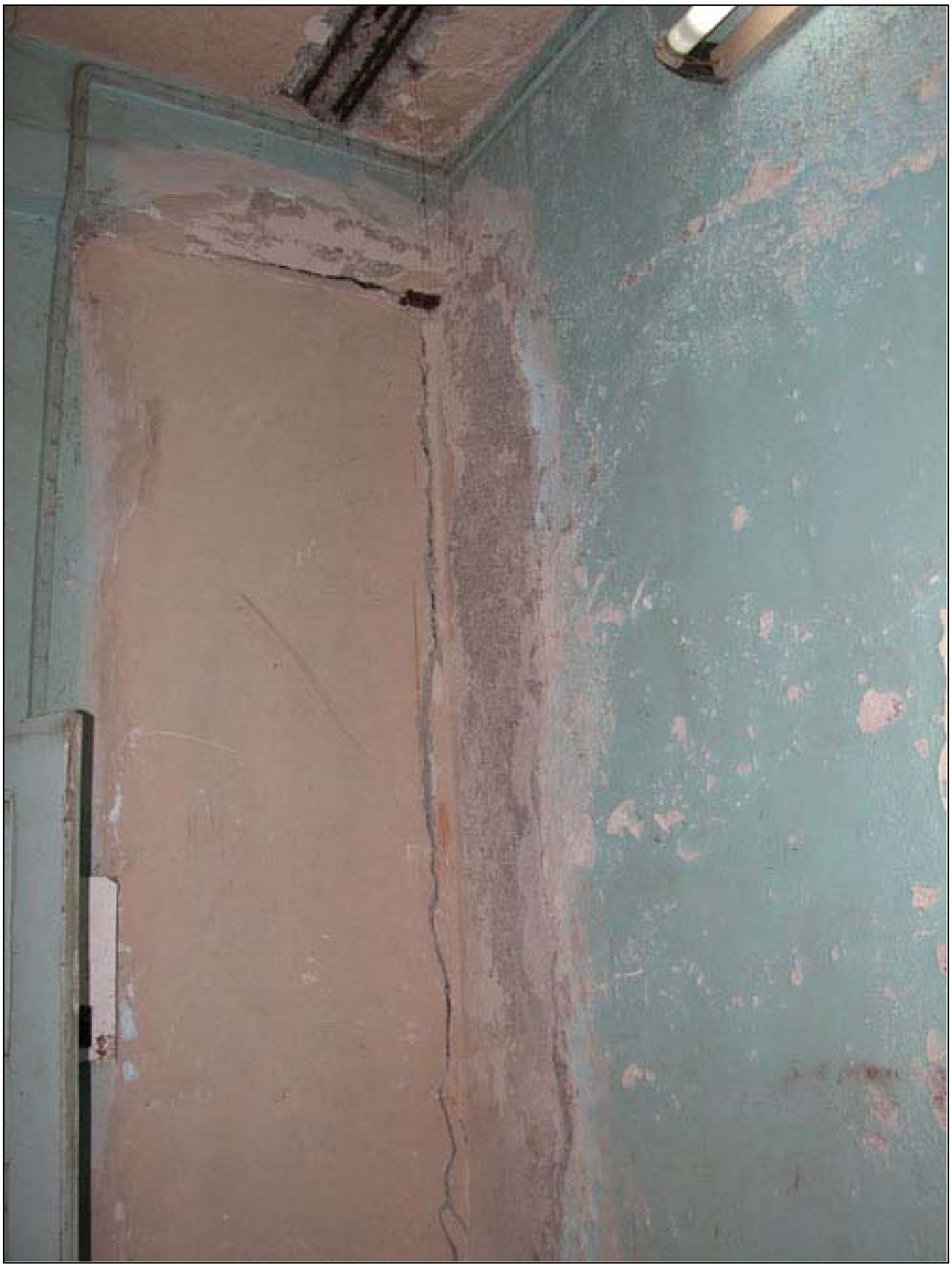


Figure 30 Masonry load bearing wall (S2-category)

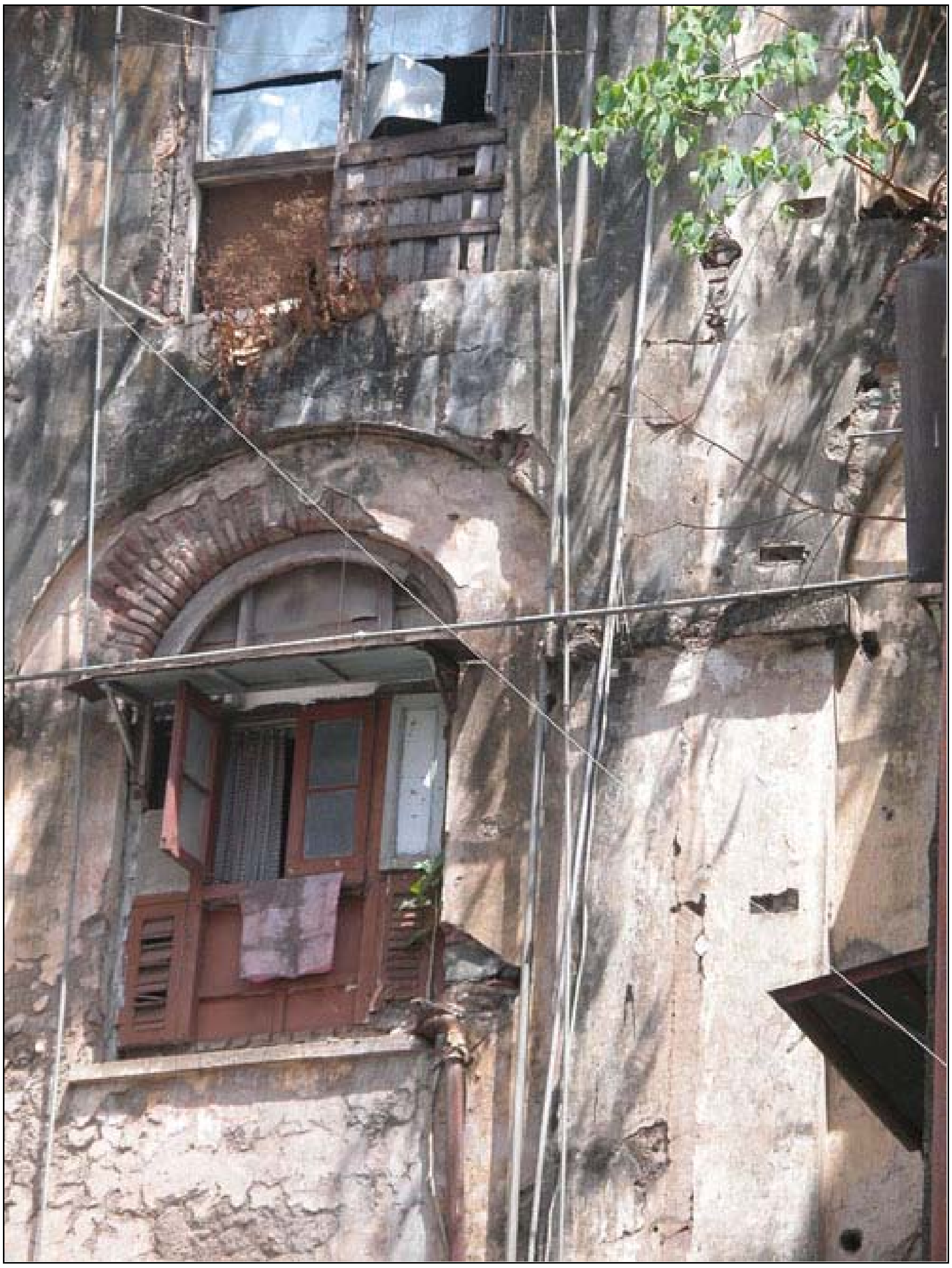


Figure 31 Masonry load bearing wall (S2-category)

Figure 32 Masonry load bearing wall (S3-category)

Figure 33 Masonry load bearing wall (S3-category)

Figure 34 Masonry load bearing wall (S3-category)

Figure 35 Masonry load bearing wall (S3-category)

Figure 36 Masonry pier (S3-category)

Figure 37 Masonry load bearing wall (S4-category)

Figure 38 Masonry load bearing wall (S5-category)

Figure 39 Masonry load bearing wall (S5-category)

Figure 40 Masonry load bearing wall (S5-category)

Figure 41 Masonry load bearing wall (S5-category)

Figure 42 RCC column (S0-category)

Figure 43 RCC column (S3-category)

Figure 44 RCC column (S3-category)

Figure 45 RCC column (S4-category)

Figure 46 RCC column (S5-category)

Figure 47 RCC column (S5-category)

Figure 48 Steel column (S0-category)

Figure 49 Steel column (S0-category)

Figure 50 Steel column (S0-category)

Figure 51 Steel column (S1-category)

Figure 52 Steel column (S1-category)

Figure 53 Steel column (S1-category)

Figure 54 Steel column (S1-category)

Figure 55 Steel column (S2-category)

Figure 56 Steel column (S5-category)

Figure 57 Steel column (S5-category)

Figure 58 Timber column (S3-category)

Figure 59 Timber column (S3-category)

Figure 60 Timber column (S3-category)

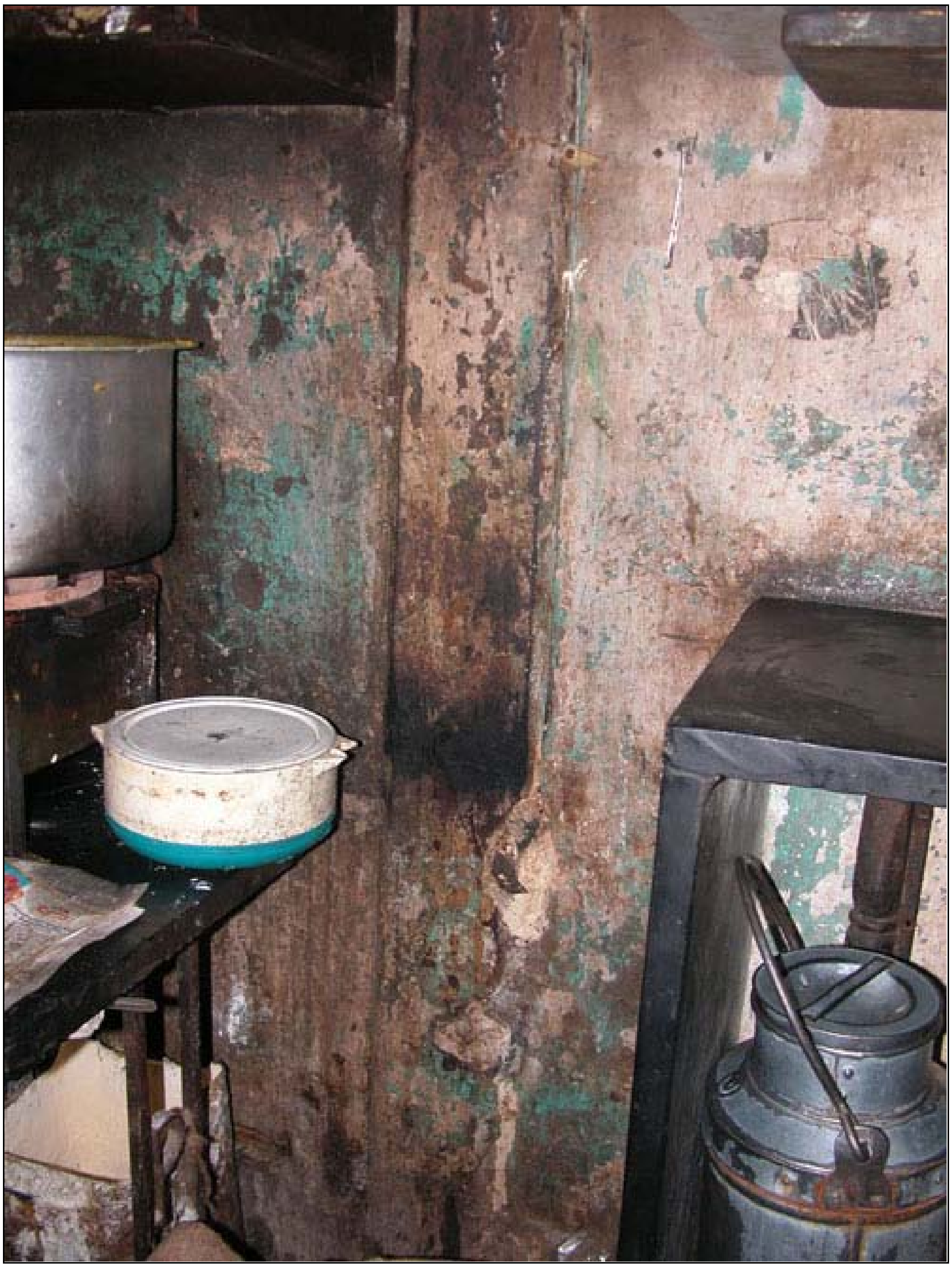


Figure 61 Timber column (S4-category)

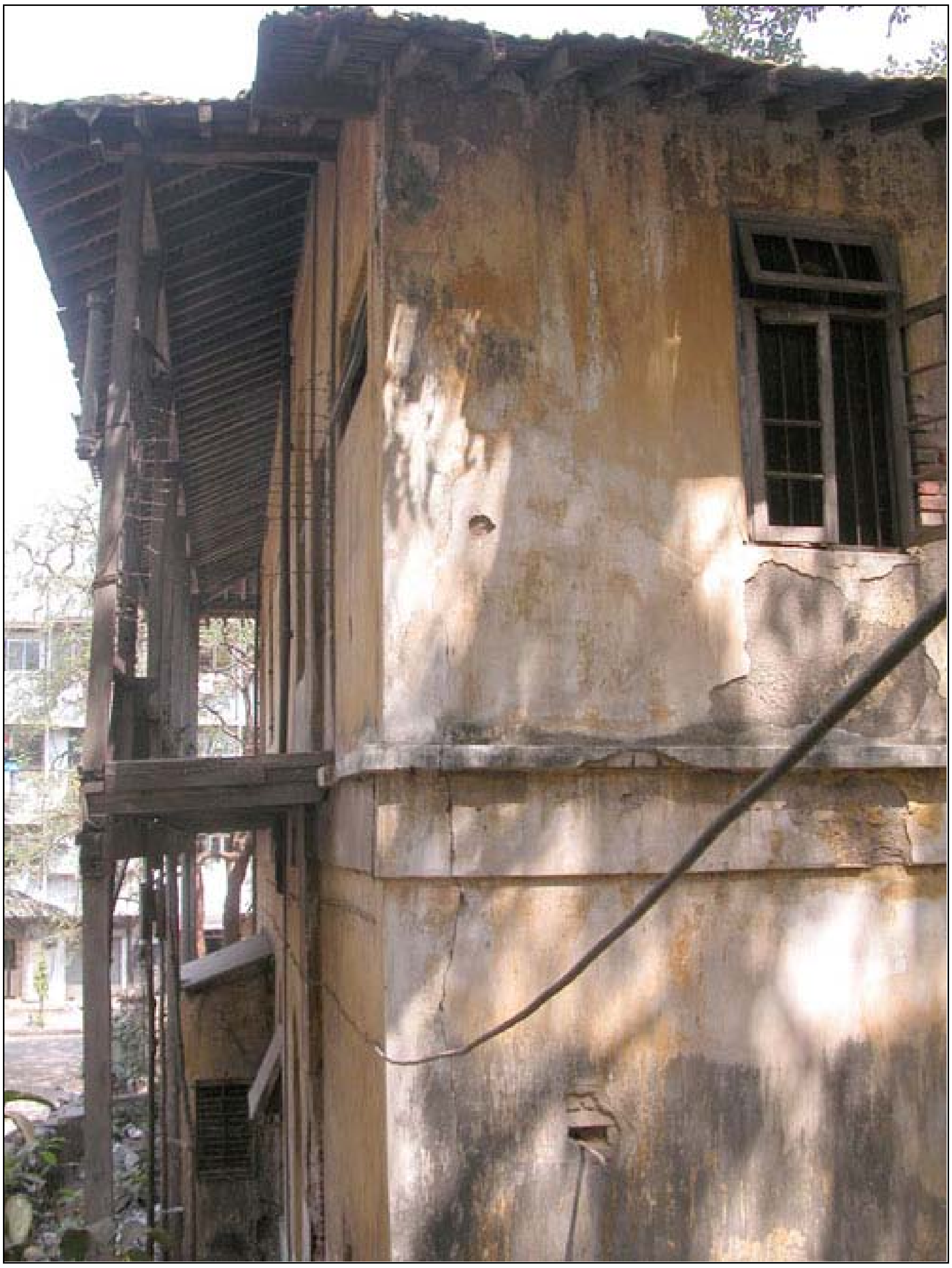


Figure 62 Timber column (S4-category)

Figure 63 Timber column (S4-category)

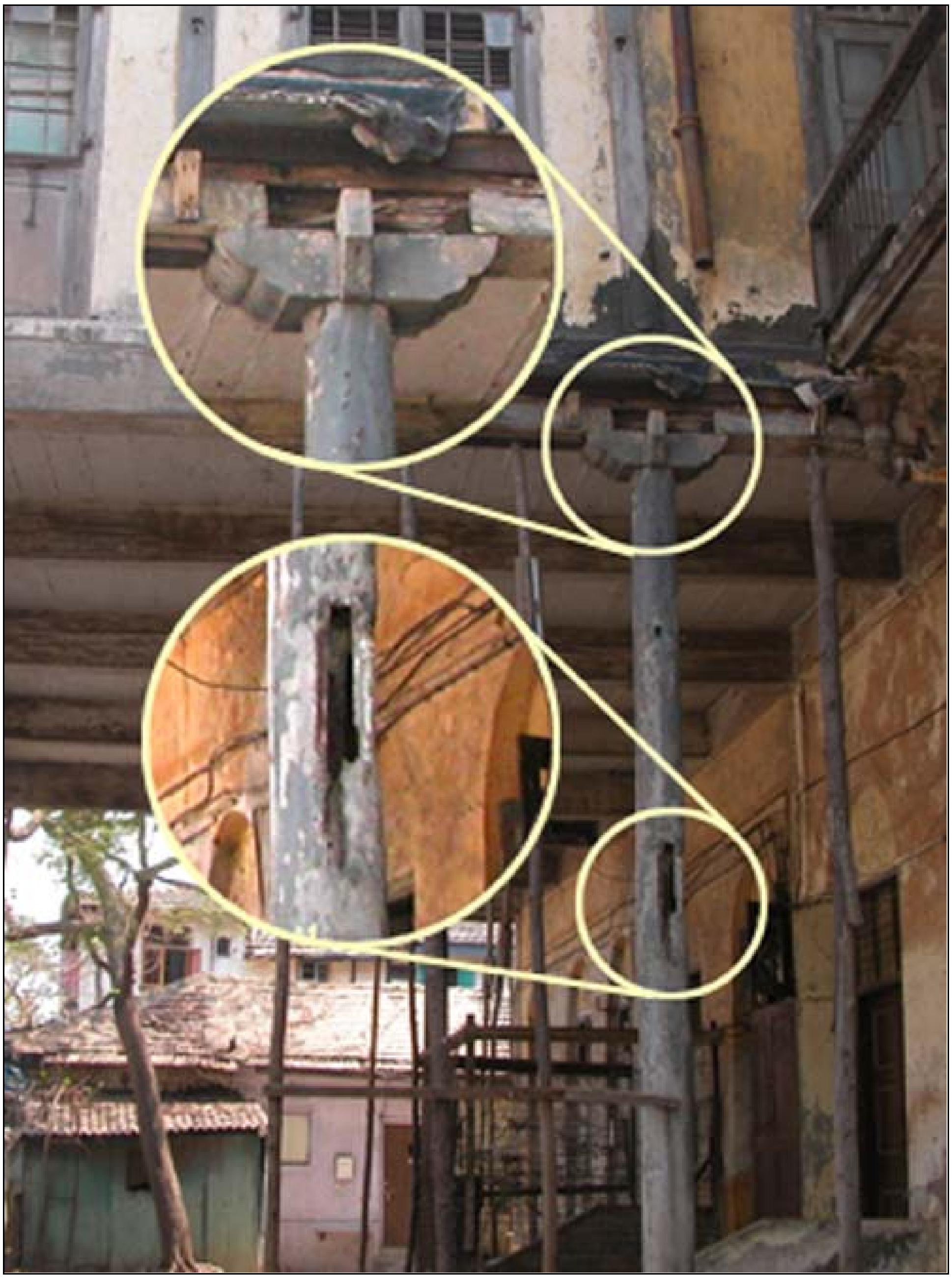


Figure 64 Timber column (S5-category)

Figure 65 Timber column (S5-category)

Figure 66 Timber column (S5-category)

Figure 67 Timber column (S5-category)

Figure 68 RCC beam (S1-category)

Figure 69 RCC beam (S2-category)

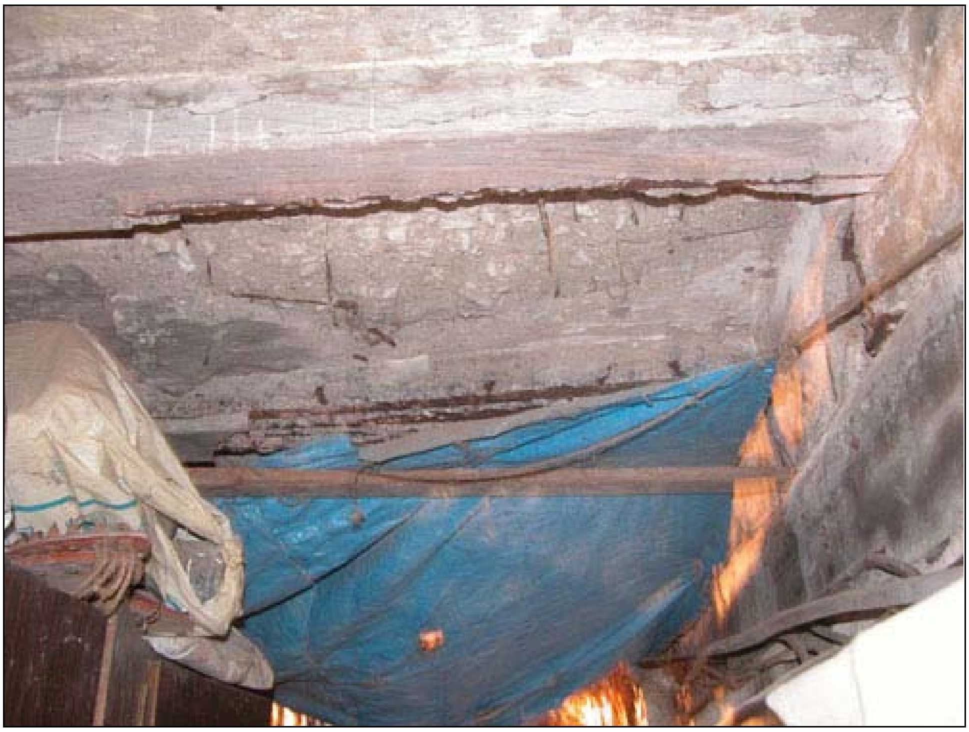


Figure 70 RCC beam (S3-category)

Figure 71 RCC beam (S3-category)

Figure 72 RCC beam (S3-category)

Figure 73 RCC beam (S3-category)

Figure 74 RCC beam (S3-category)

Figure 75 RCC beam (S4-category)

Figure 76 Steel beam (S3-category)

Figure 77 Steel beam-column junction (S3-category)

Figure 78 Steel beam (S3-category)

Figure 79 Steel beam (S5-category)

Figure 80 Steel beam-column junction (S5-category)

Figure 81 Timber beam (S3-category)

Figure 82 Timber beam (S3-category)

Figure 83 Timber beam (S3-category)

Figure 84 Timber beam (S3-category)

Figure 85 Timber beam (S3-category)

Figure 86 Timber beam (S3-category)

Figure 87 Timber beam (S4-category)

Figure 88 Timber beam (S4-category)

Figure 89 Timber beam (S5-category)

Figure 90 Timber beam (S5-category)

Figure 91 RCC joists (S2-category)

Figure 92 Timber joists (S3-category)

Figure 93 Timber joists (S3-category)

Figure 94 Cast stone slab (S0-category)

Figure 95 Cast stone slab (S0-category)

Figure 96 Cast stone slab (S1-category)

Figure 97 Cast stone slab (S2-category)

Figure 98 Cast stone slab (S3-category)

Figure 99 Cast stone slab (S3-category)

Figure 100 Ladicoba slab (S2-category)

Figure 101 Ladicoba slab (S3-category)

Figure 102 Ladicoba slab (S4-category)

Figure 103 RCC slab (S4-category)

Appendix C

Capacity curves for calculating the permissible load calculations are:

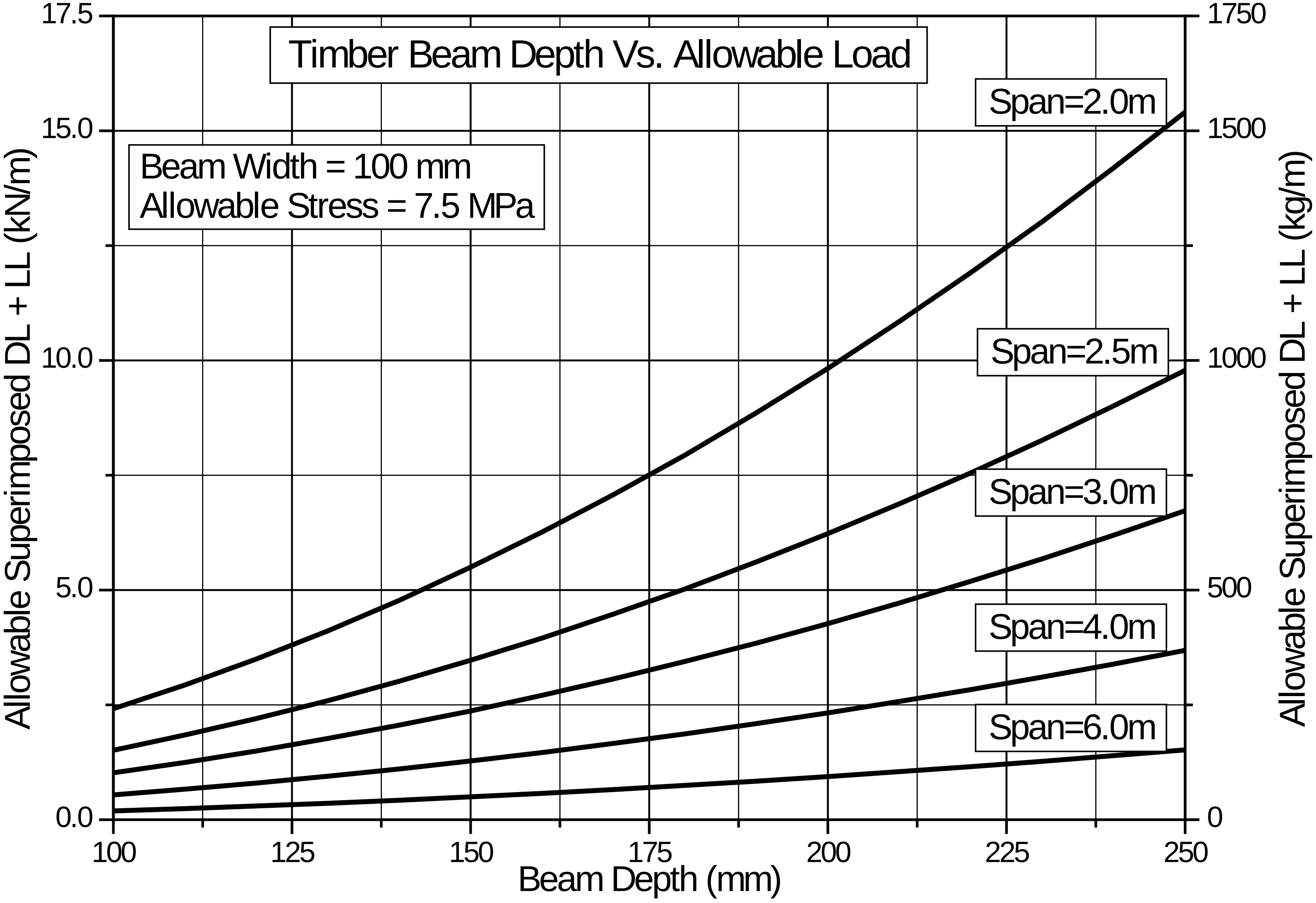


Figure 1: Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress = 7.5 MPa)

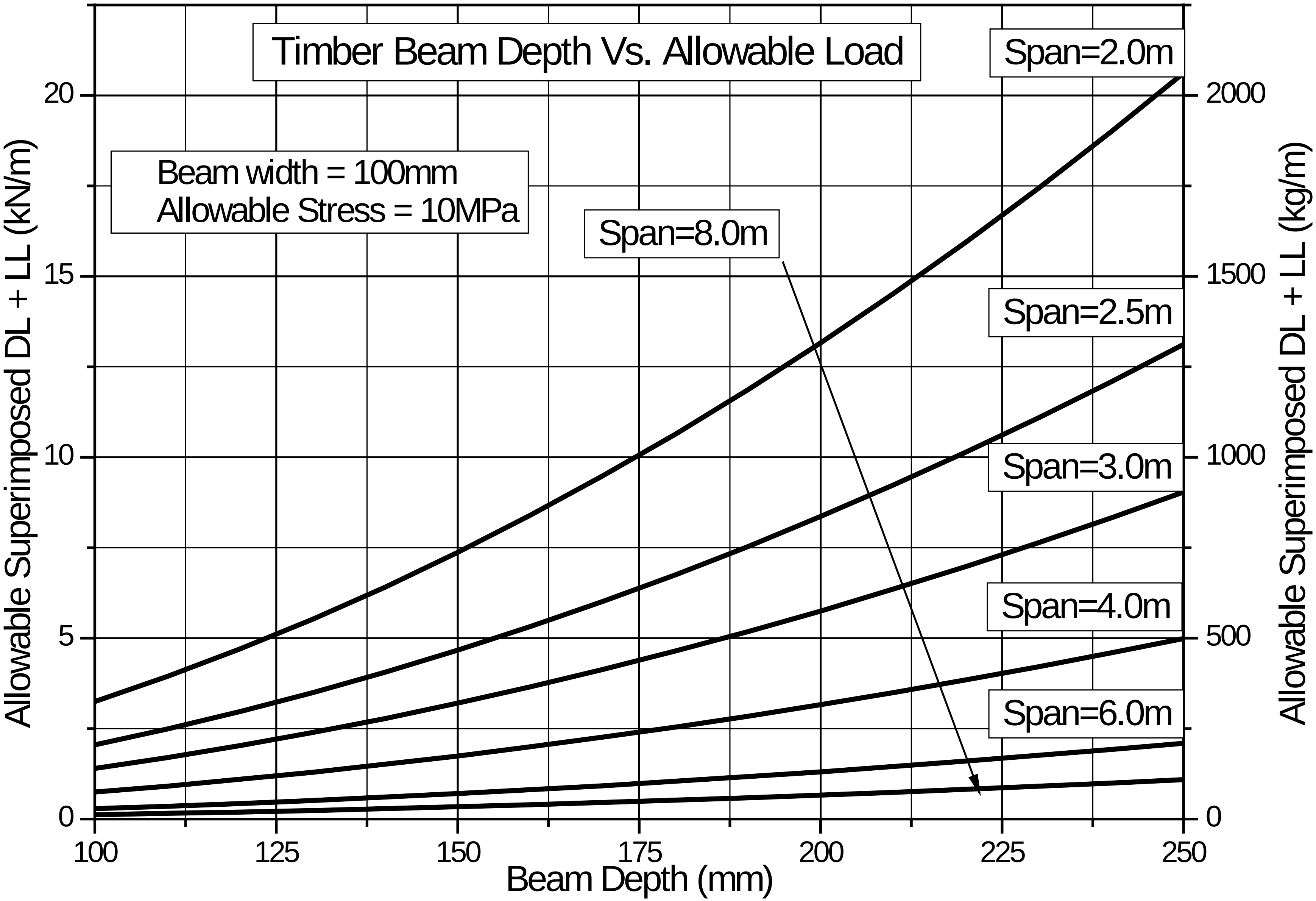


Figure 2: Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress = 10 MPa)

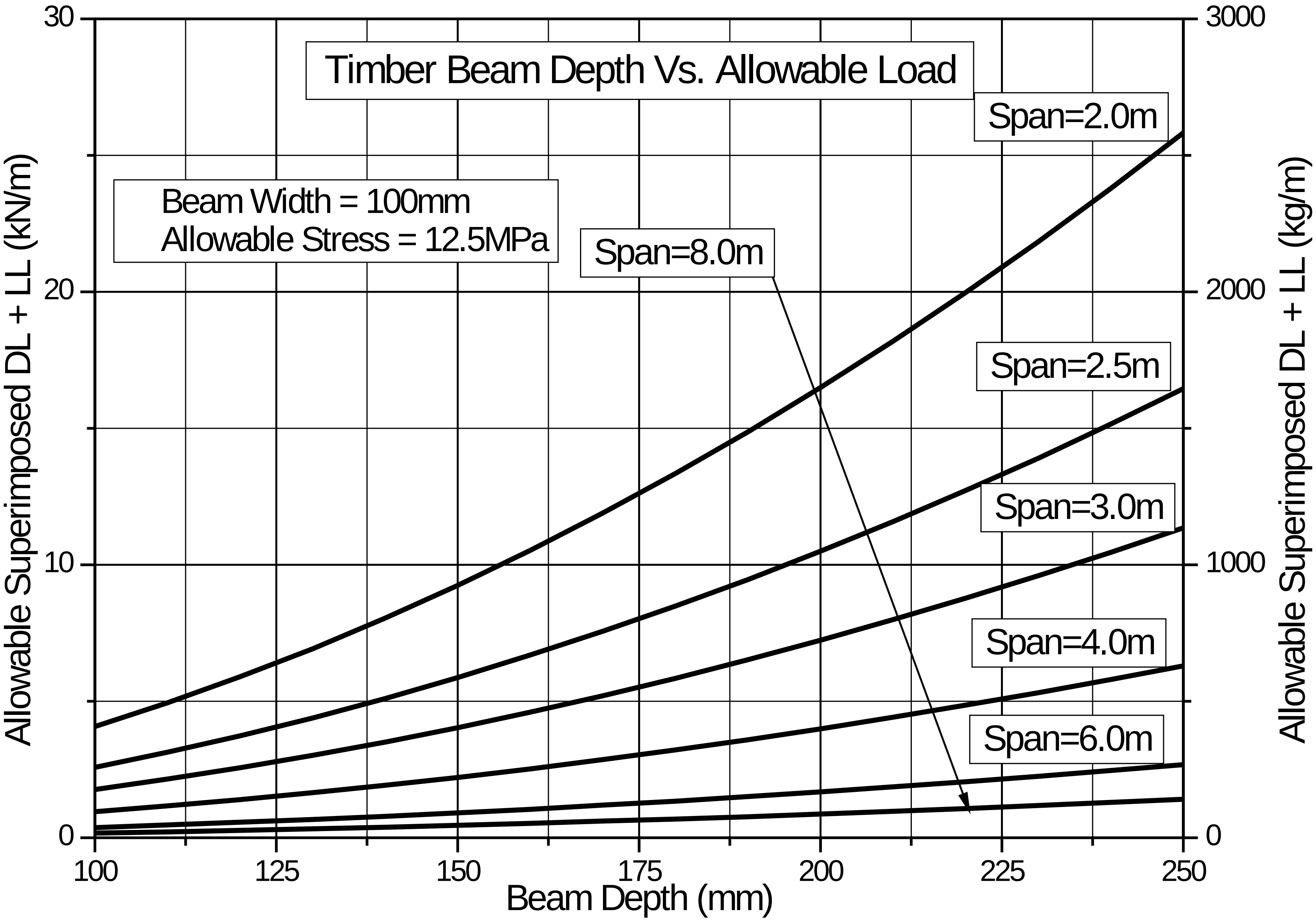


Figure 3 Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress = 12.5 MPa)

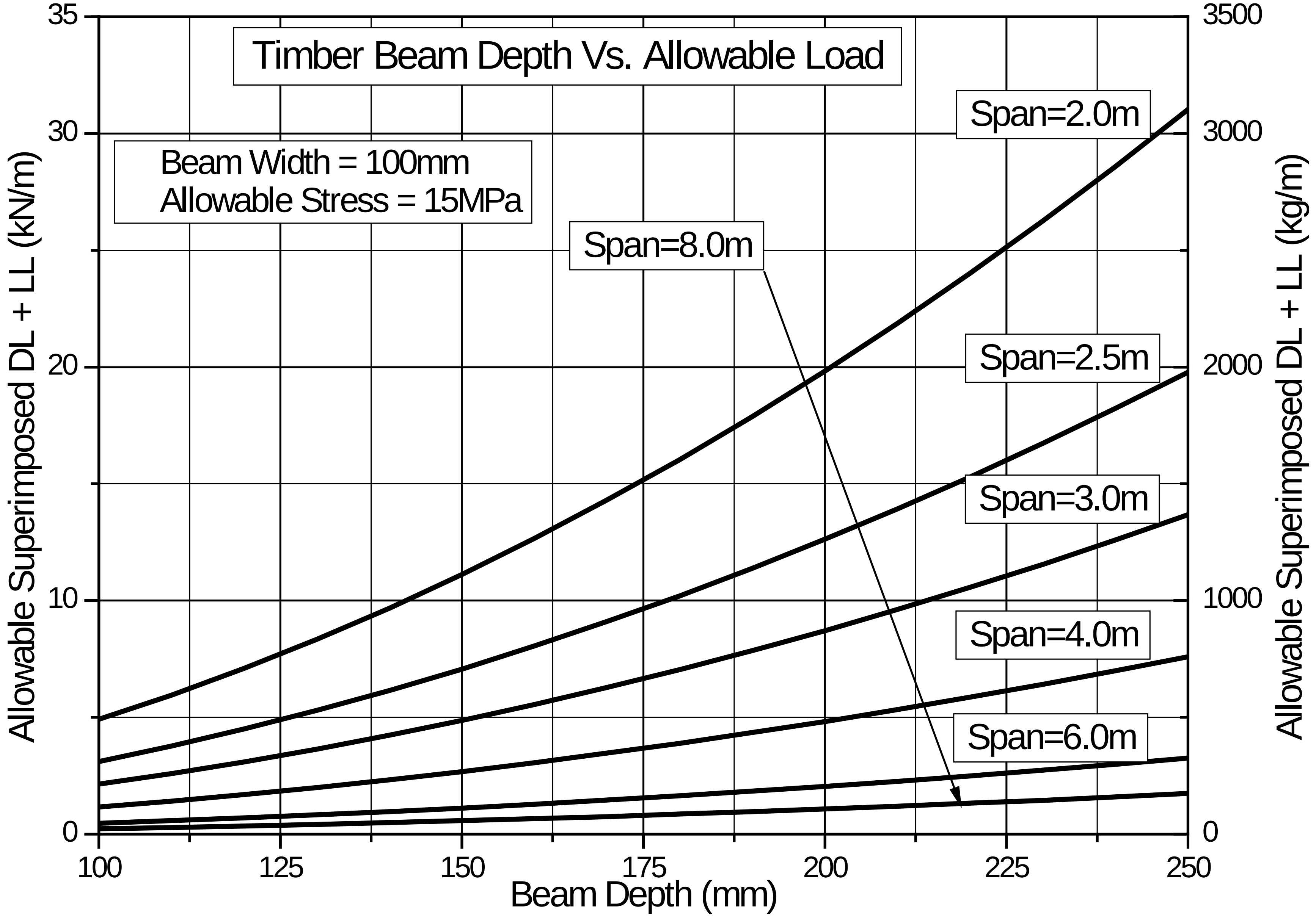


Figure 4: Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress = 15 MPa)

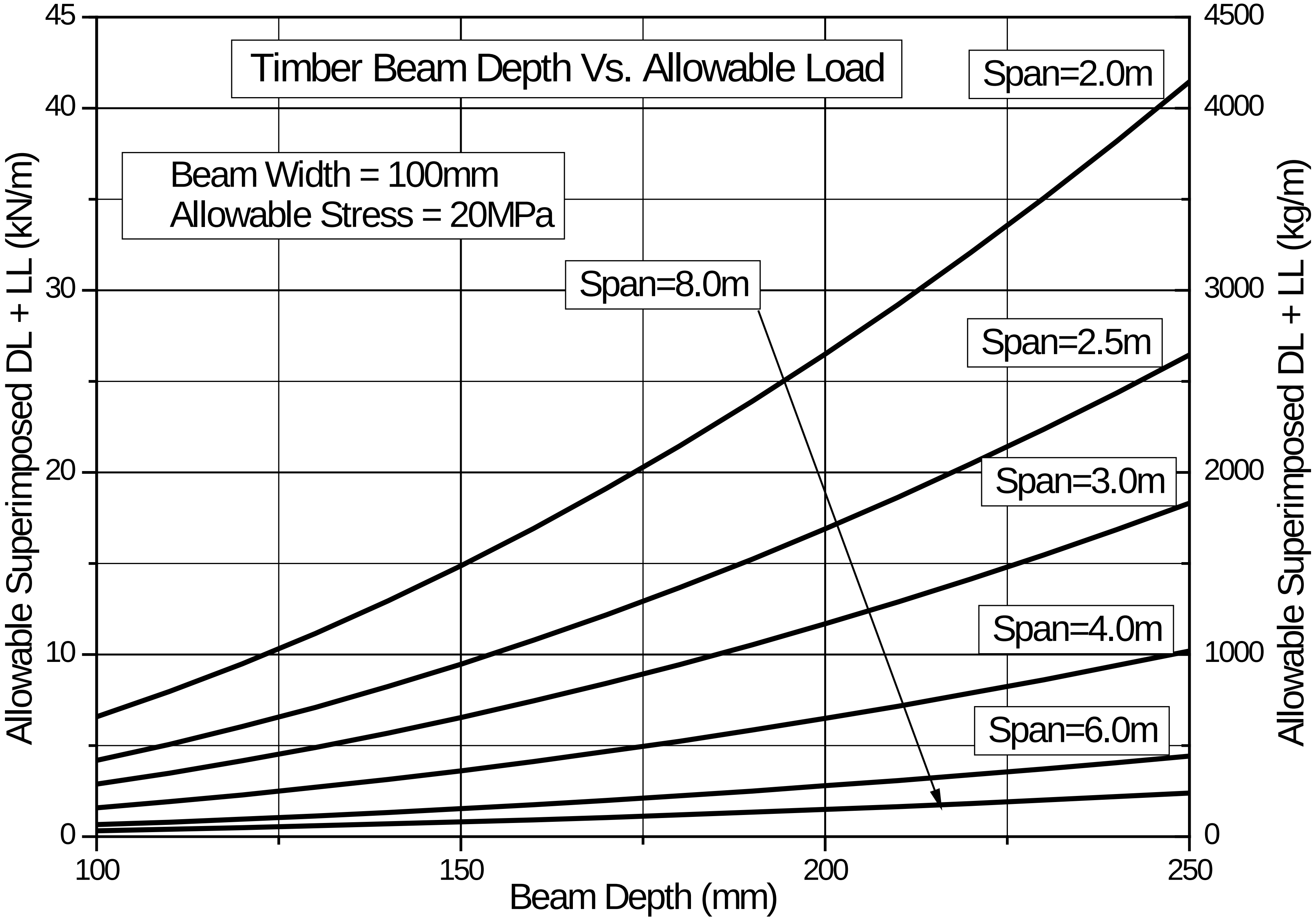


Figure 5: Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress =20 MPa)

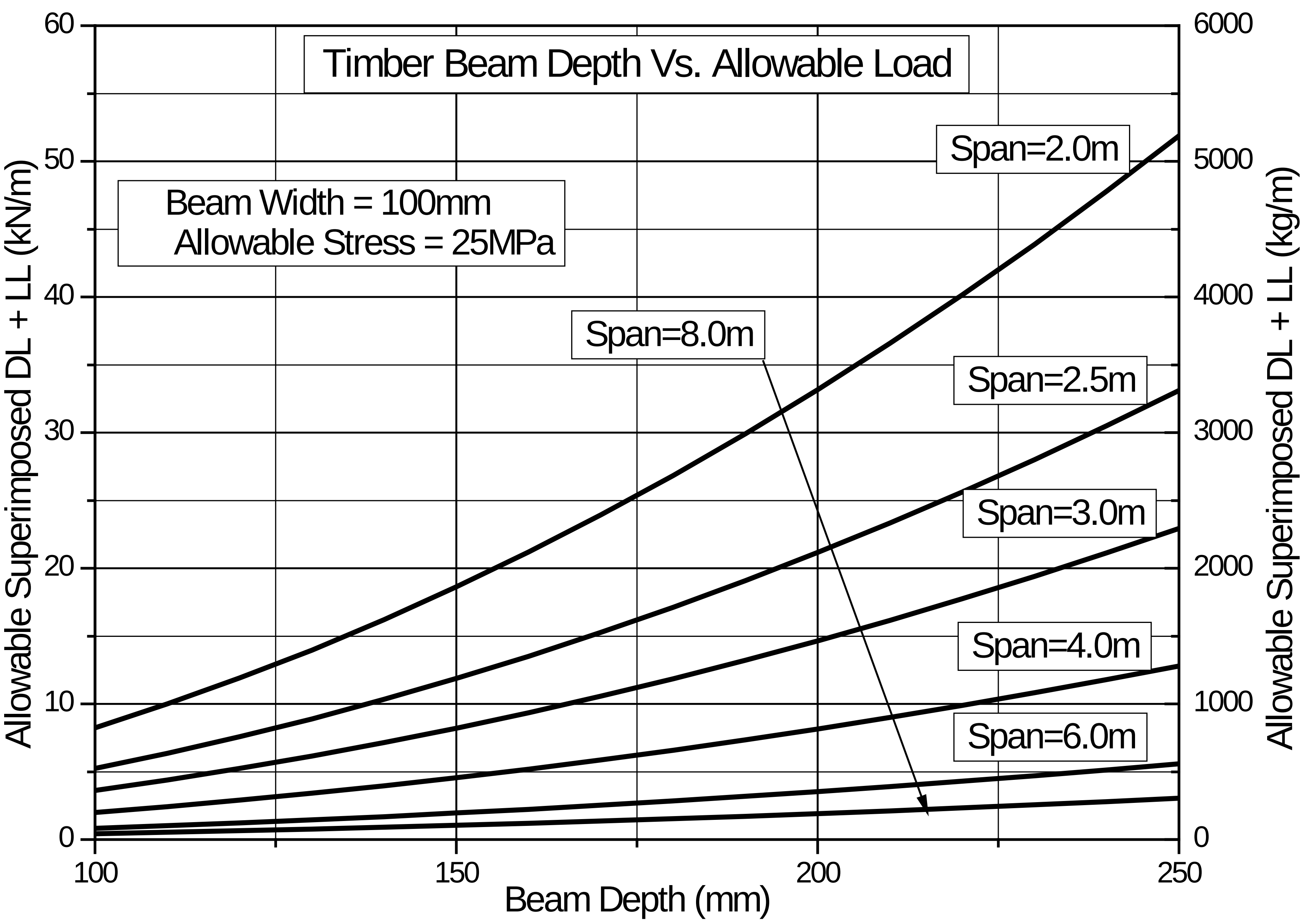


Figure 6: Timber Beam Depth vs. Allowable Load (Beam width = 100 mm & Allowable Stress = 25 MPa)

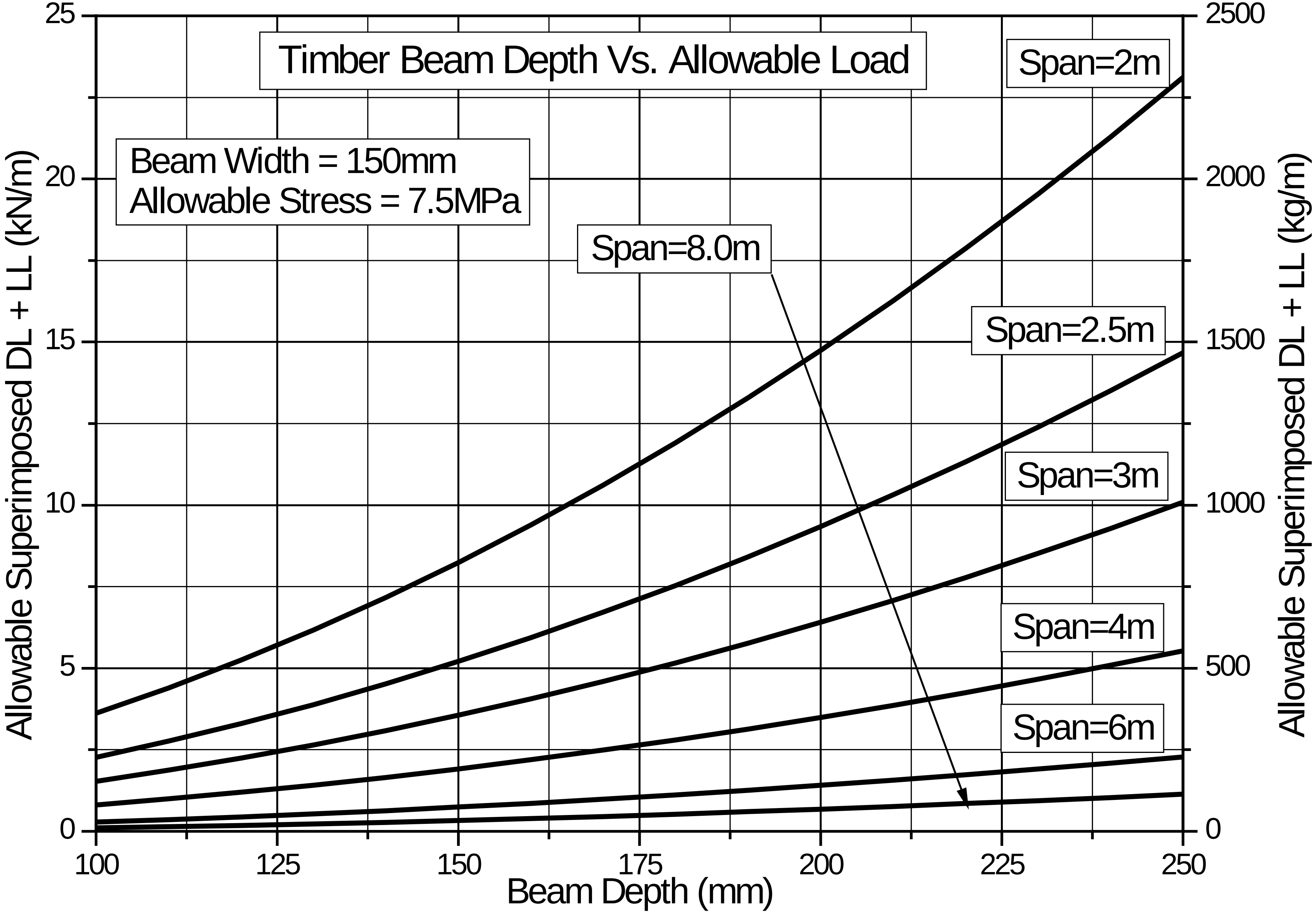


Figure 7: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress = 7.5 MPa)

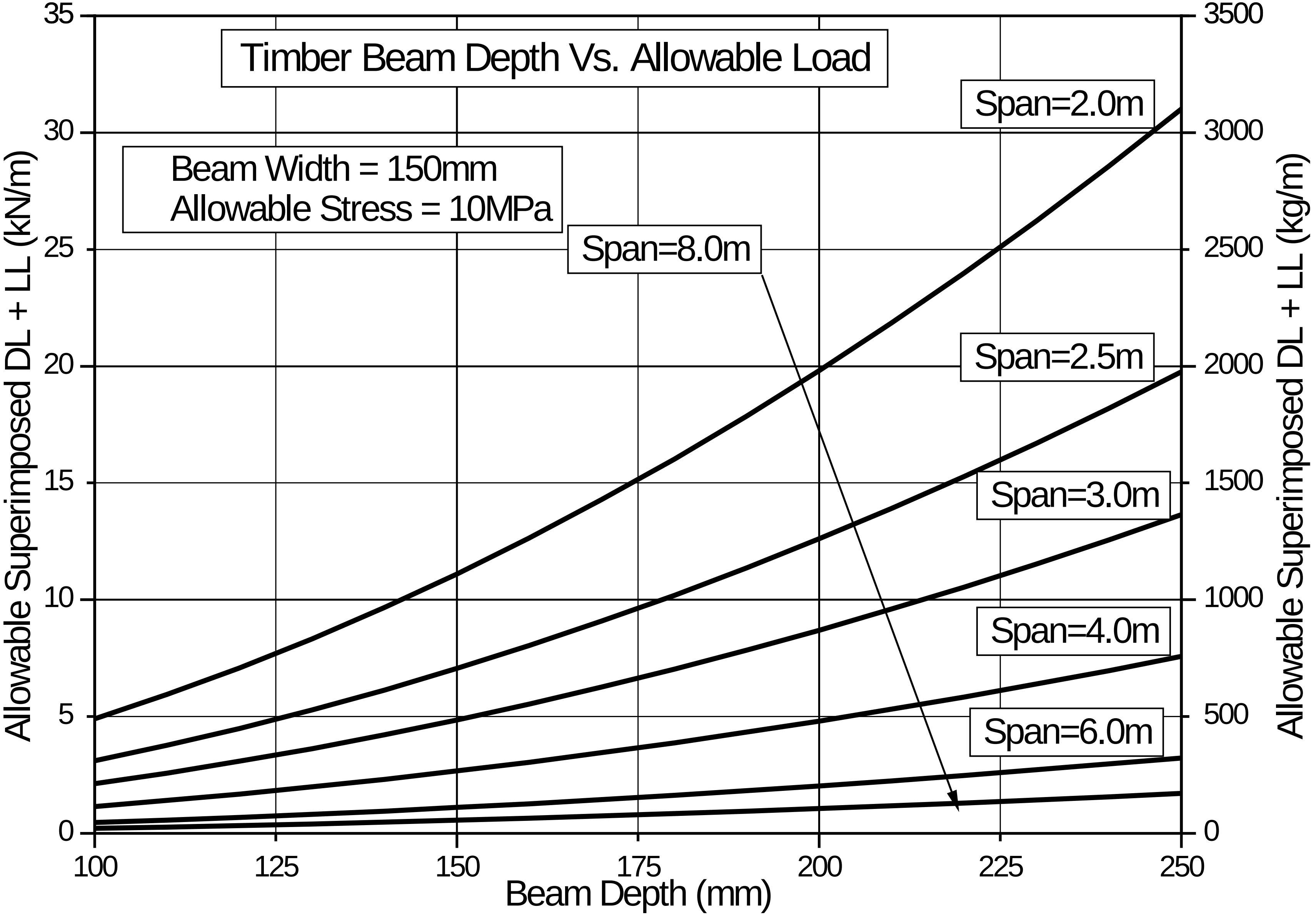


Figure 8: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress = 10 MPa)

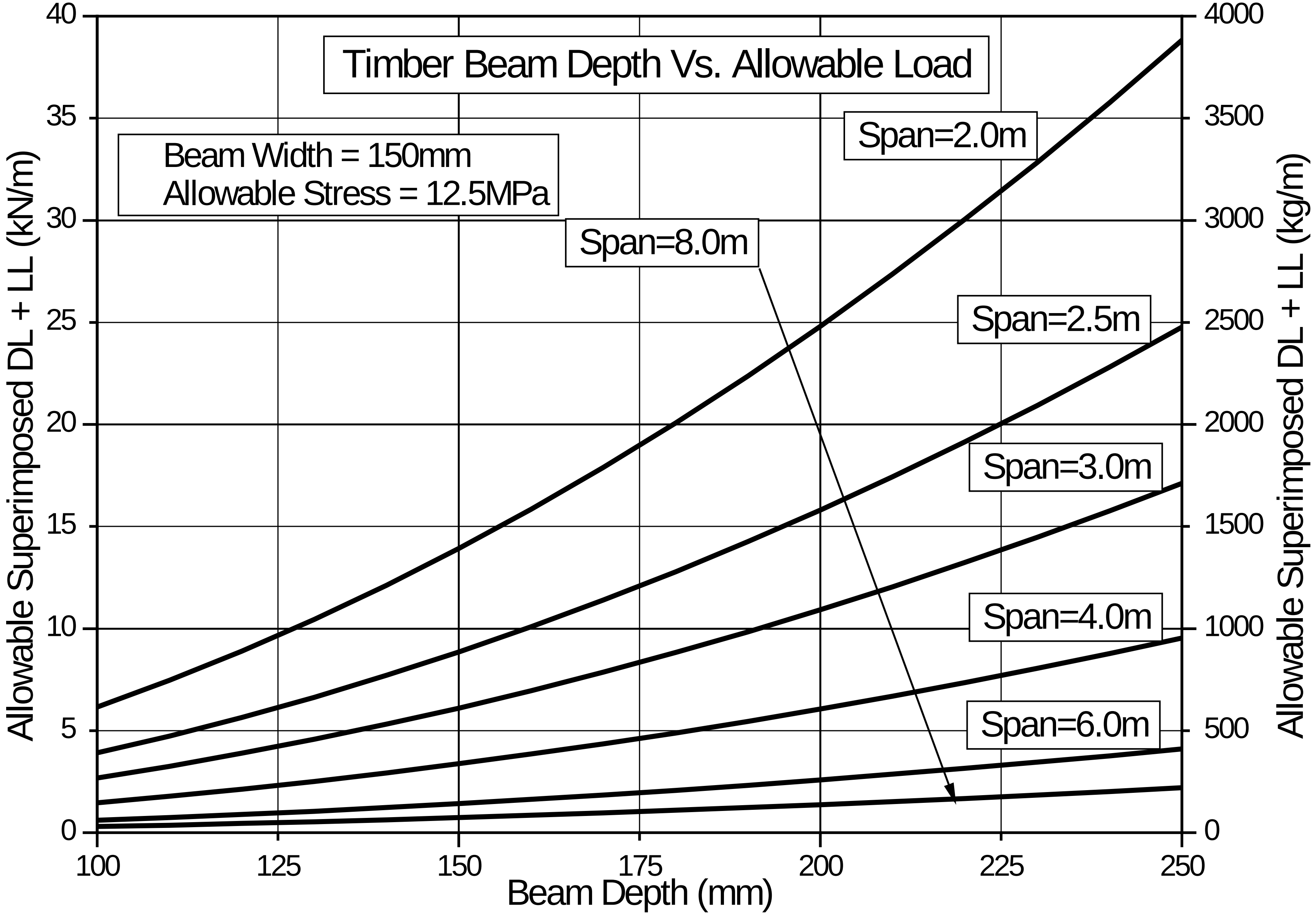


Figure 9: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress =12.5 MPa)

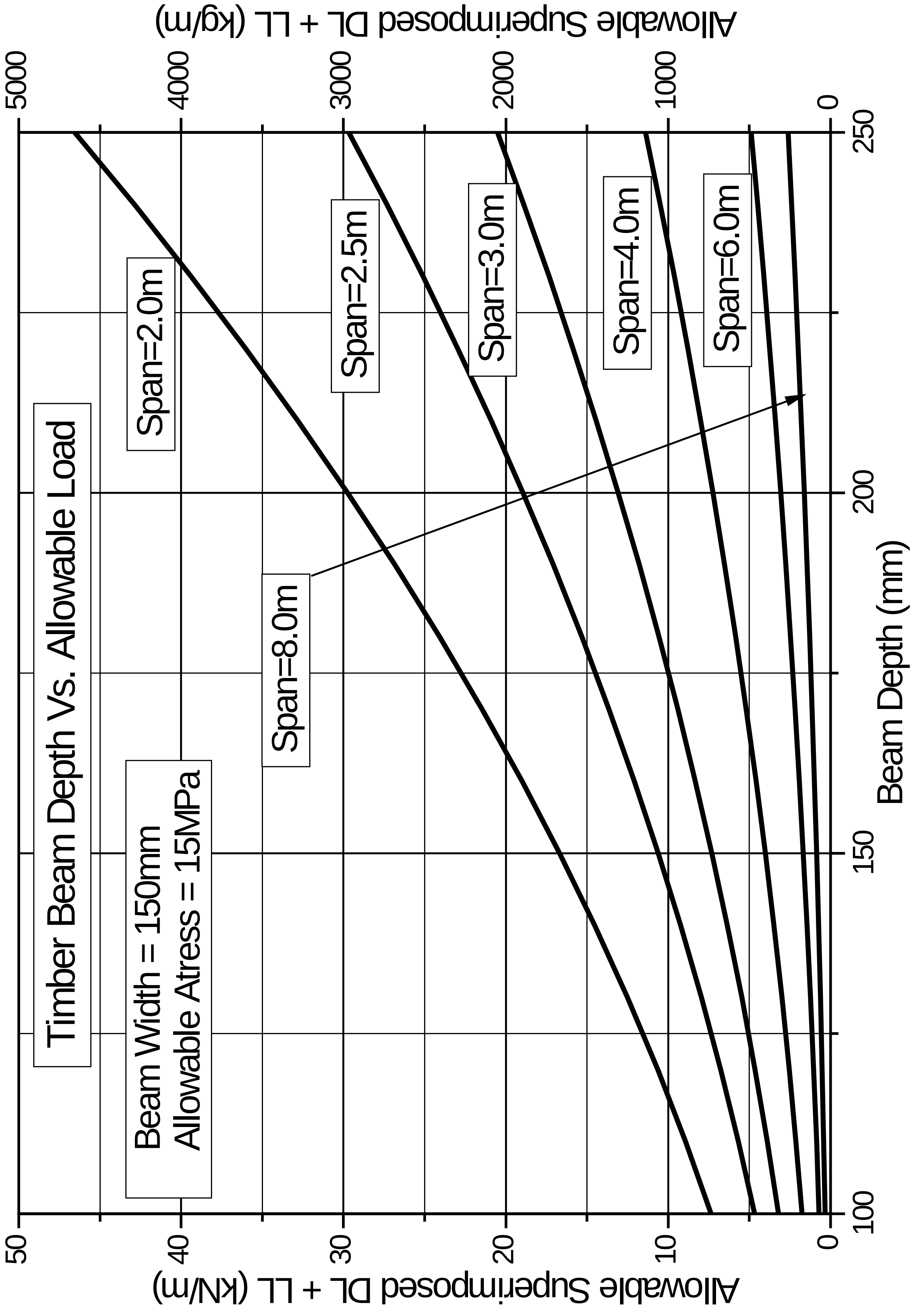


Figure 10: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress =15 MPa)

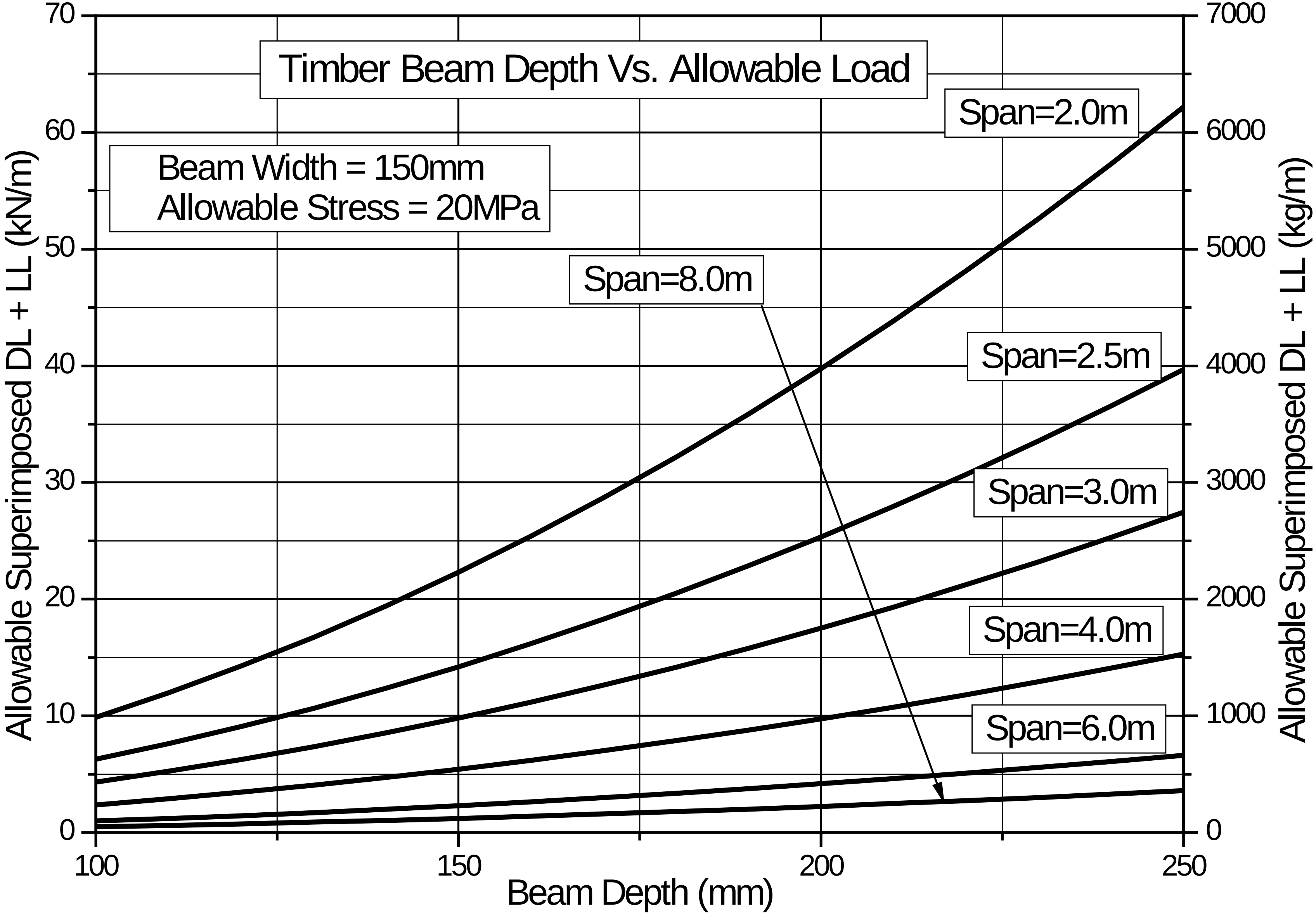


Figure 11: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress = 20 MPa)

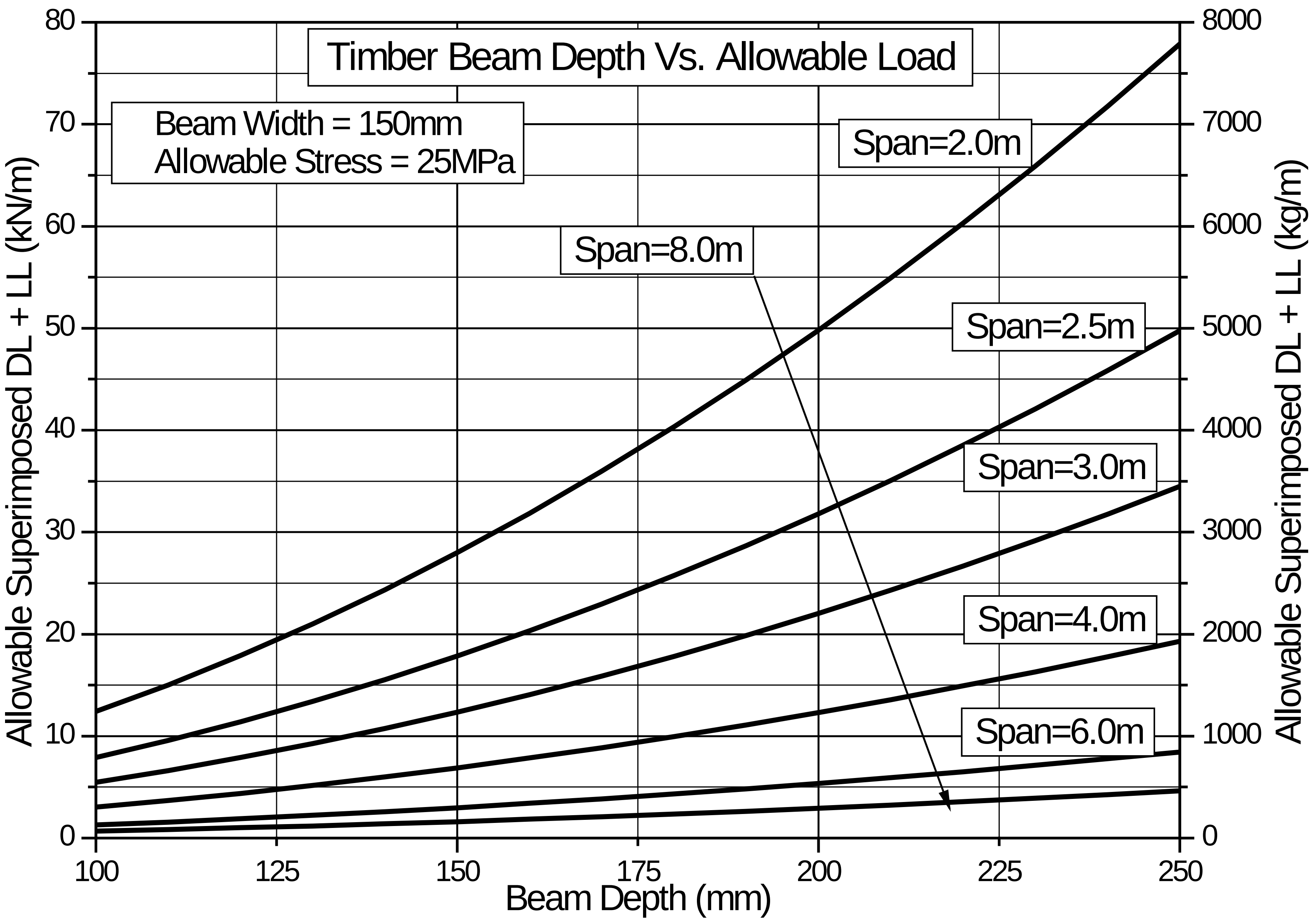


Figure 12: Timber Beam Depth vs. Allowable Load (Beam width = 150 mm & Allowable Stress = 25 MPa)

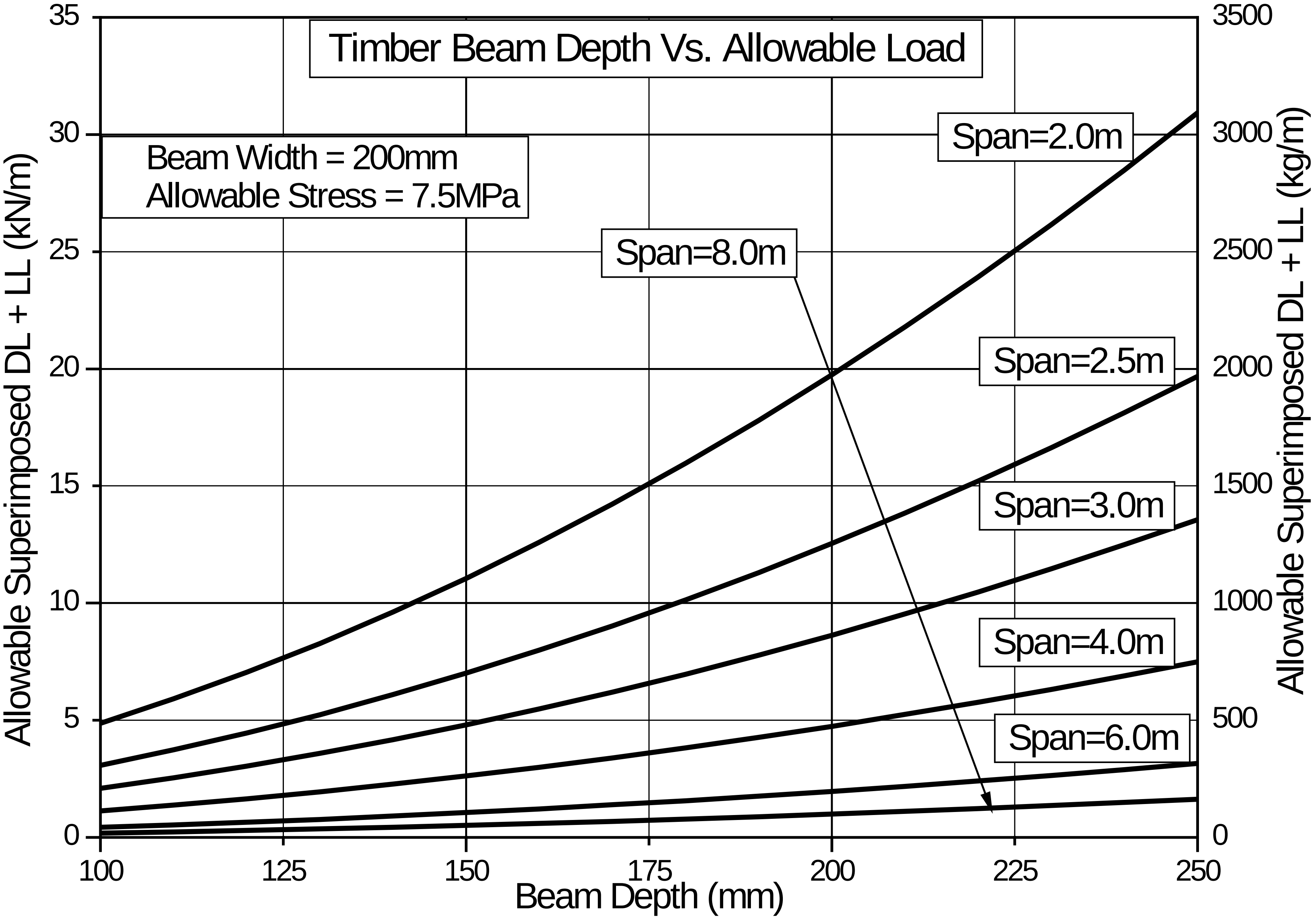


Figure 13: Timber Beam Depth vs. Allowable Load (Beam width = 200 mm & Allowable Stress = 7.5 MPa)

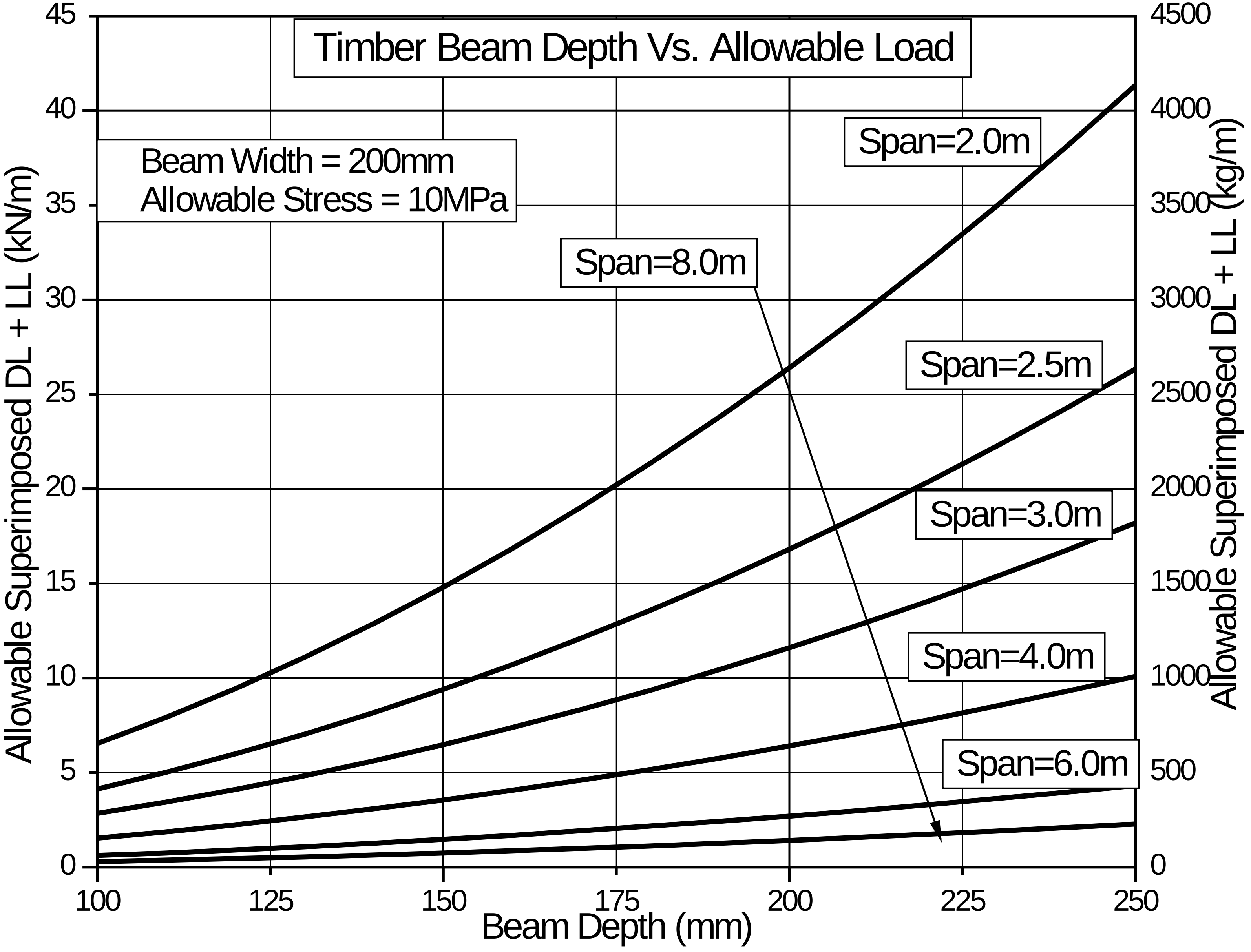


Figure 14: Timber Beam Depth vs. Allowable Load (Beam width =200 mm & Allowable Stress = 10 MPa)

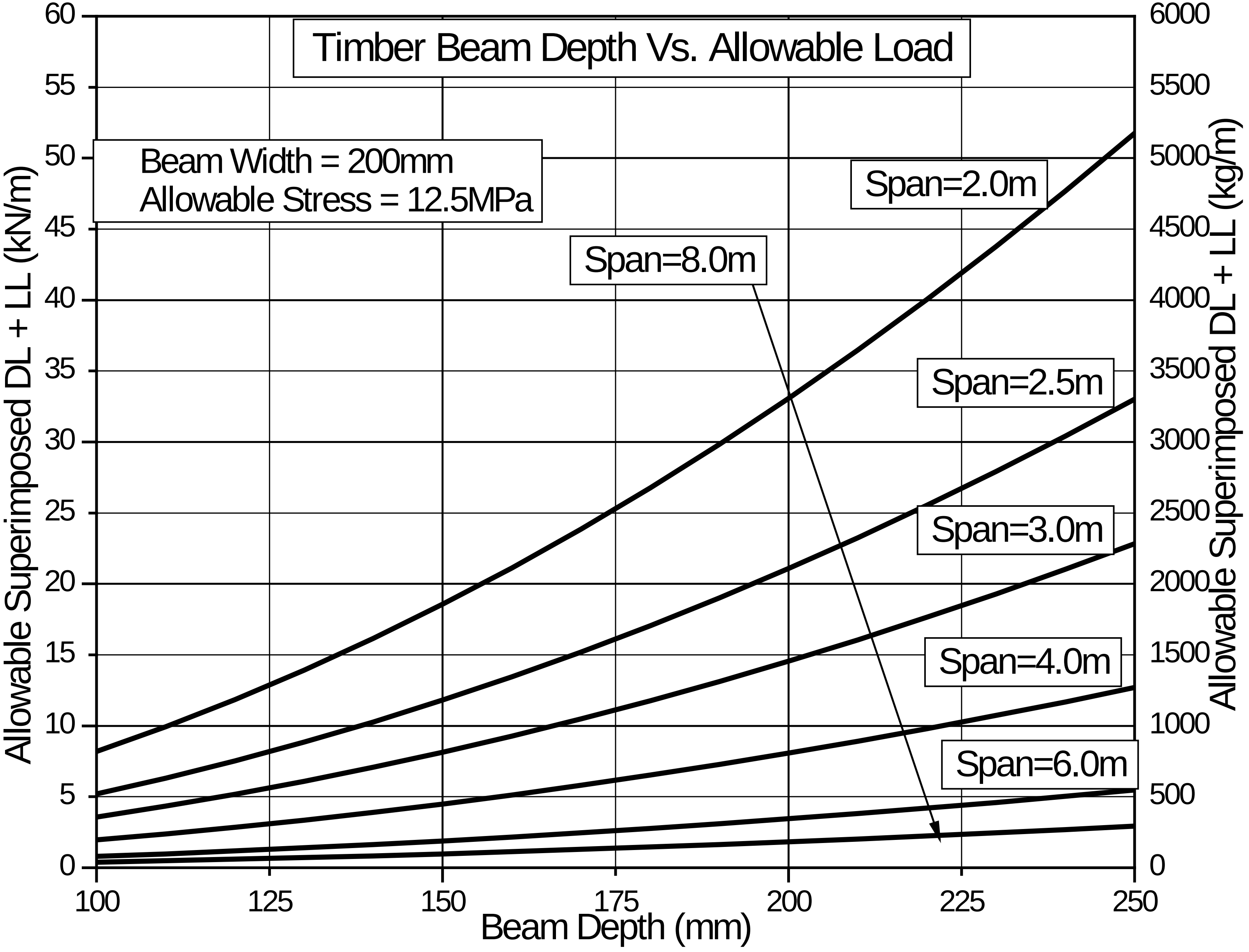


Figure 15 Timber Beam Depth vs. Allowable Load (Beam width =200 mm & Allowable Stress = 12.5 MPa)

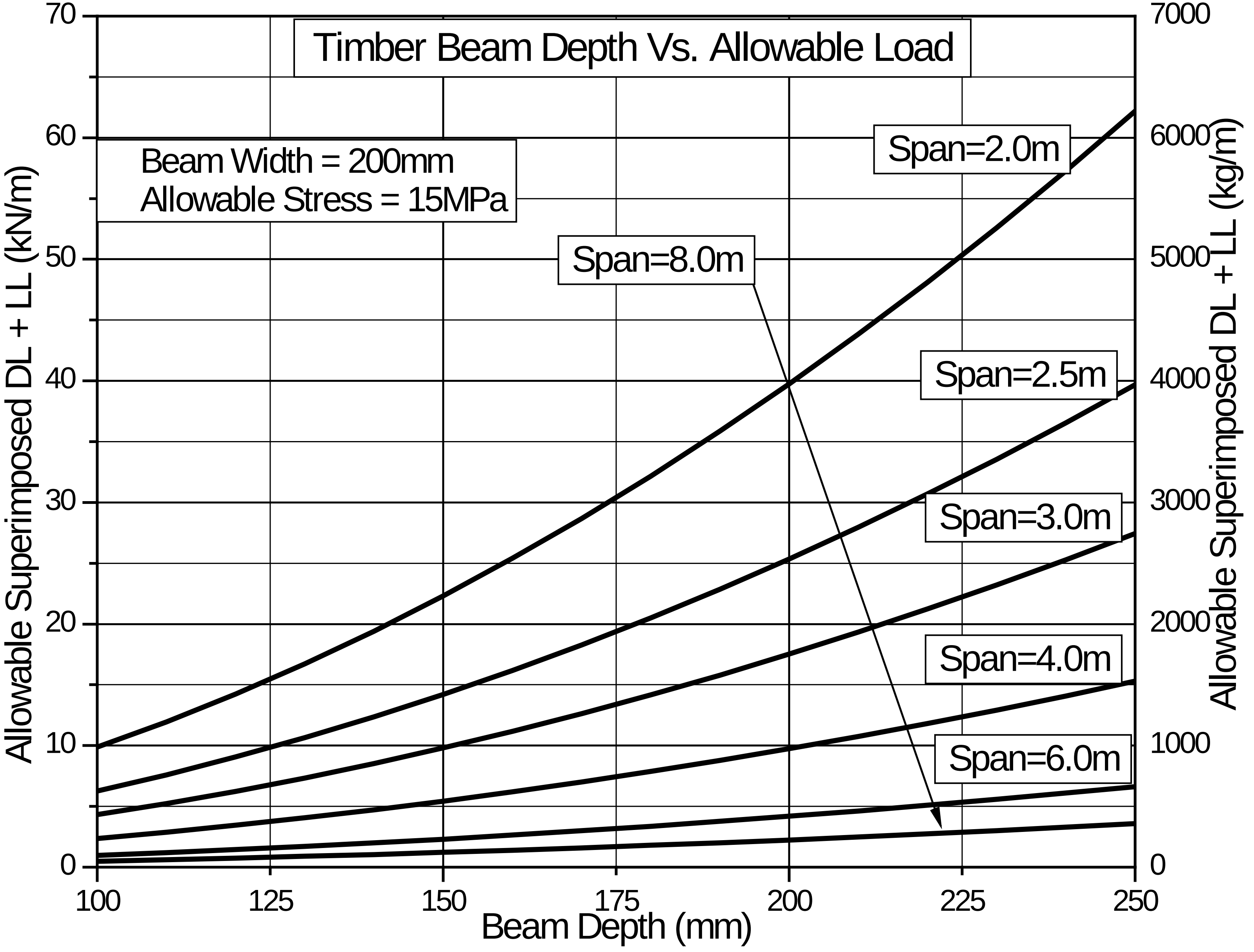


Figure 16: Timber Beam Depth vs. Allowable Load (Beam width =200 mm & Allowable Stress = 15 MPa)

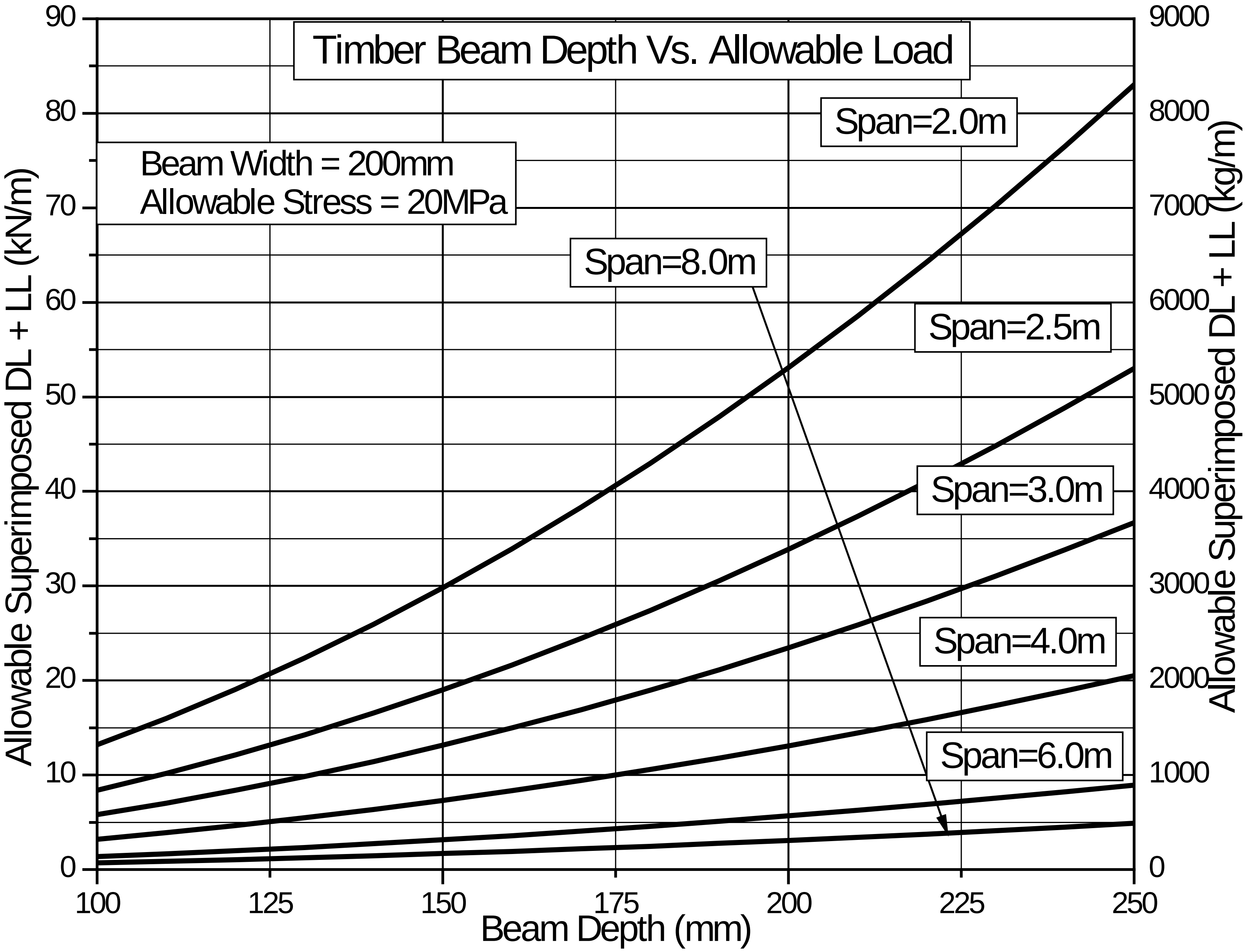


Figure 17: Timber Beam Depth vs. Allowable Load (Beam width =200 mm & Allowable Stress =20 MPa)

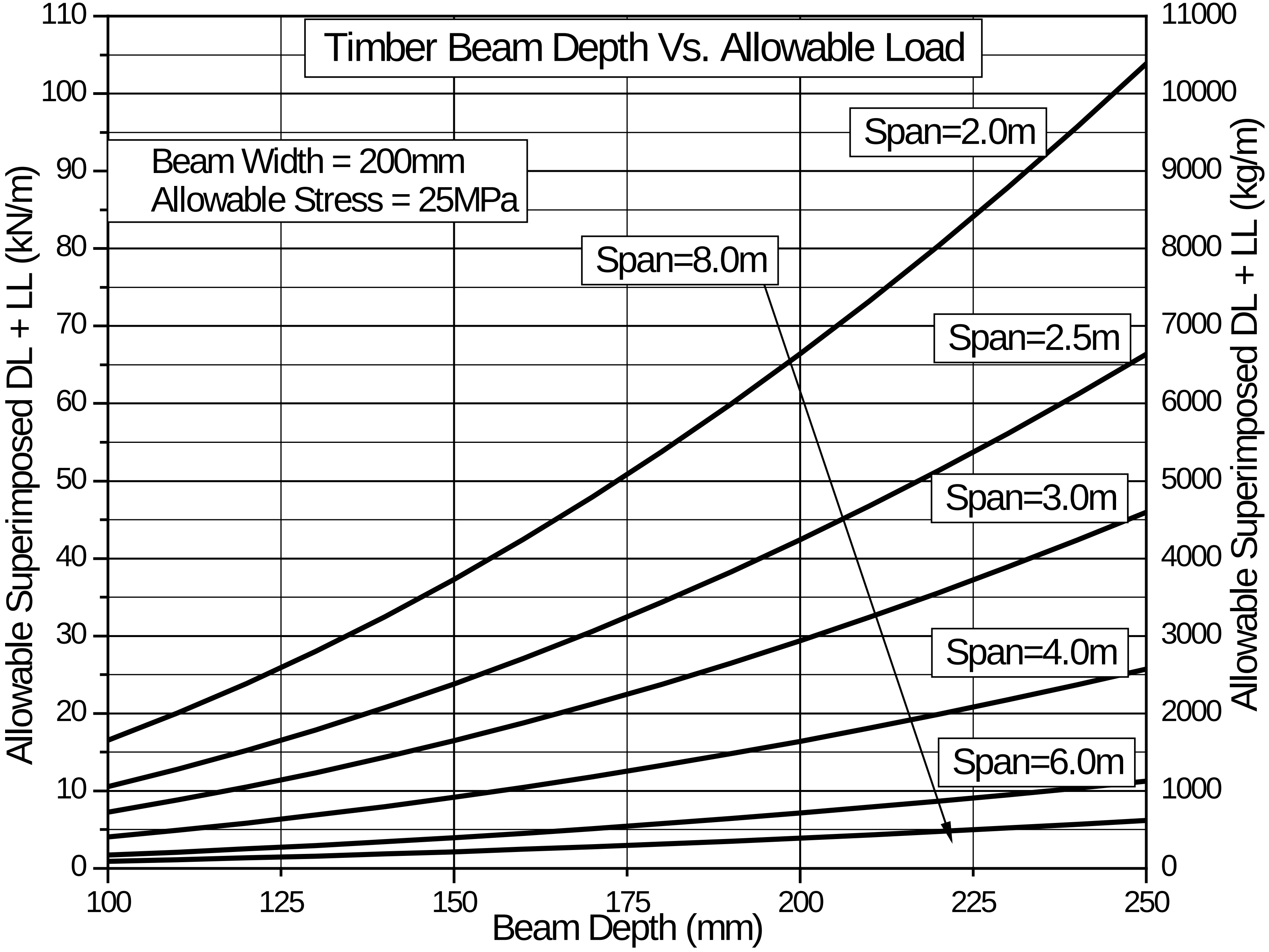


Figure 18: Timber Beam Depth vs. Allowable Load (Beam width = 200 mm & Allowable Stress = 25 MPa)

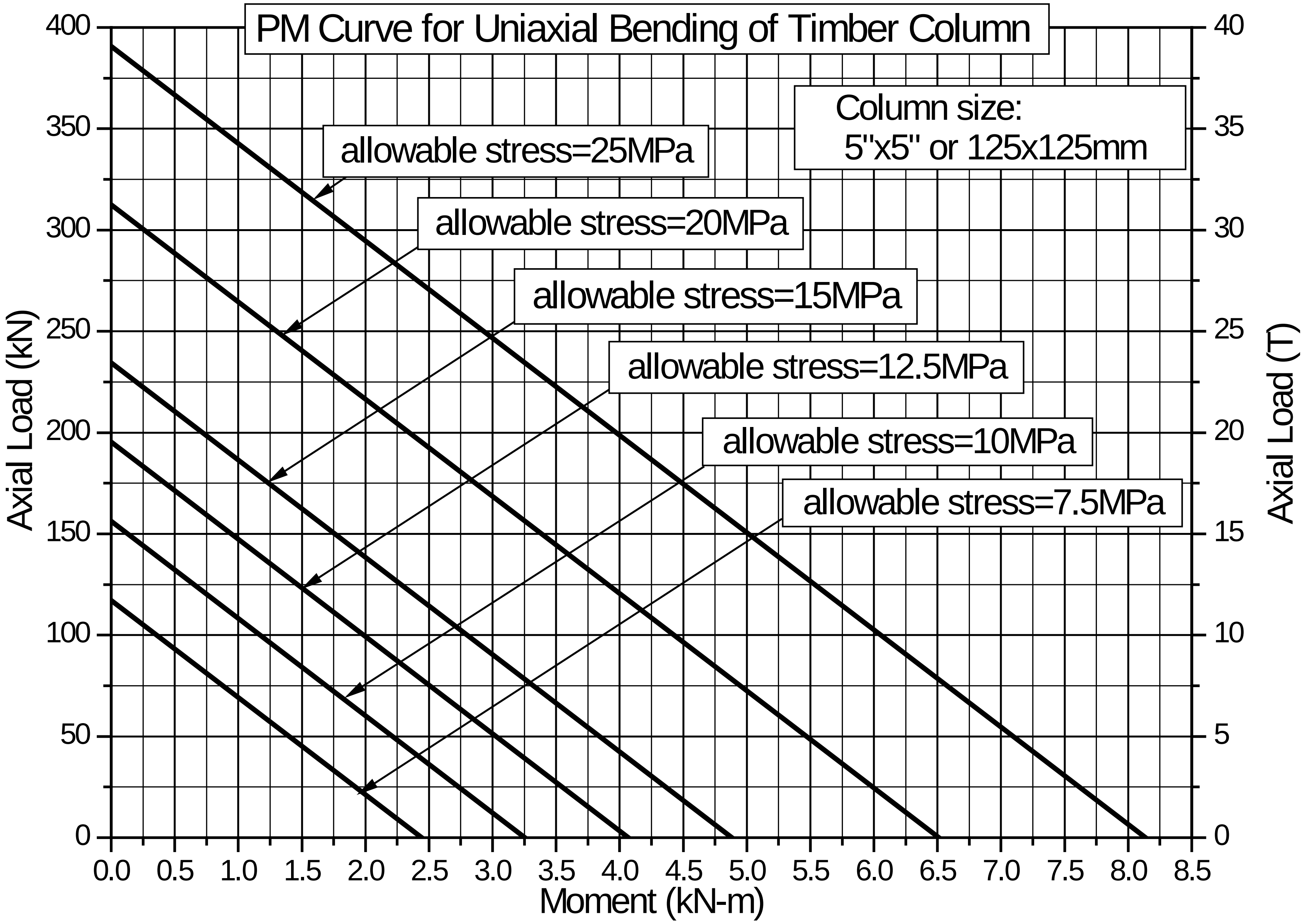


Figure 19: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 125 x 125 mm)

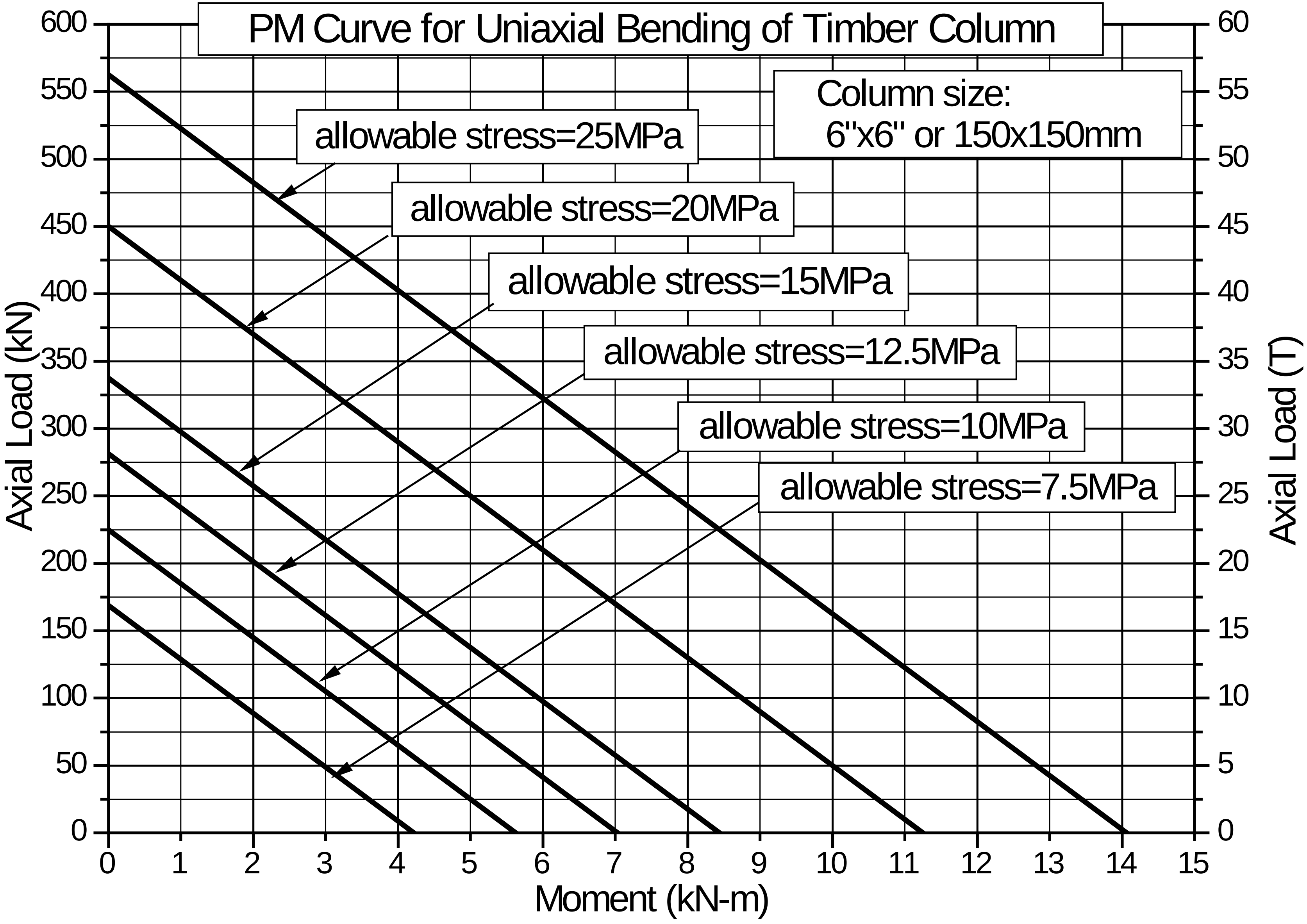


Figure 20: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 150 x 150 mm)

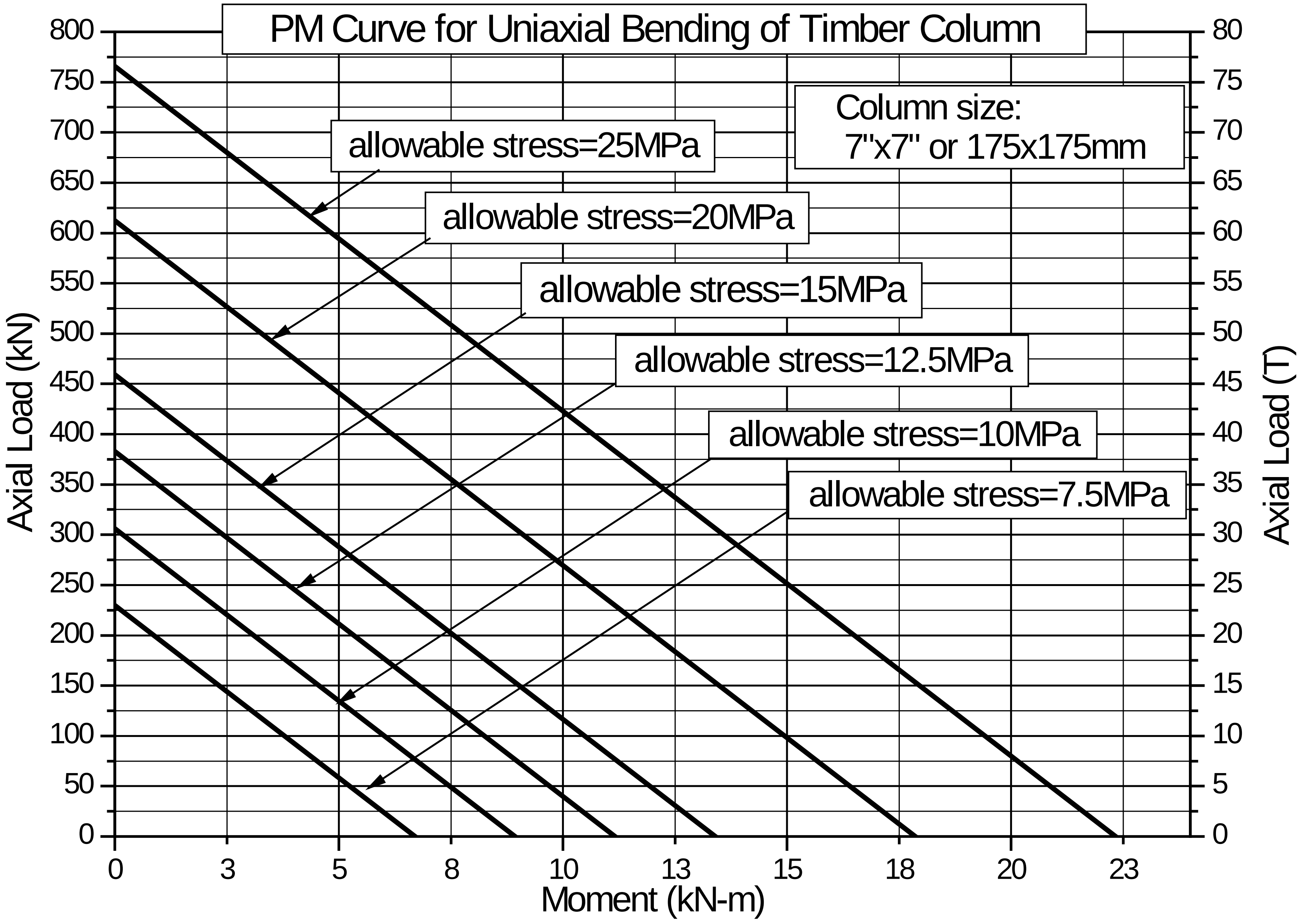


Figure 21: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 175 x 175 mm)

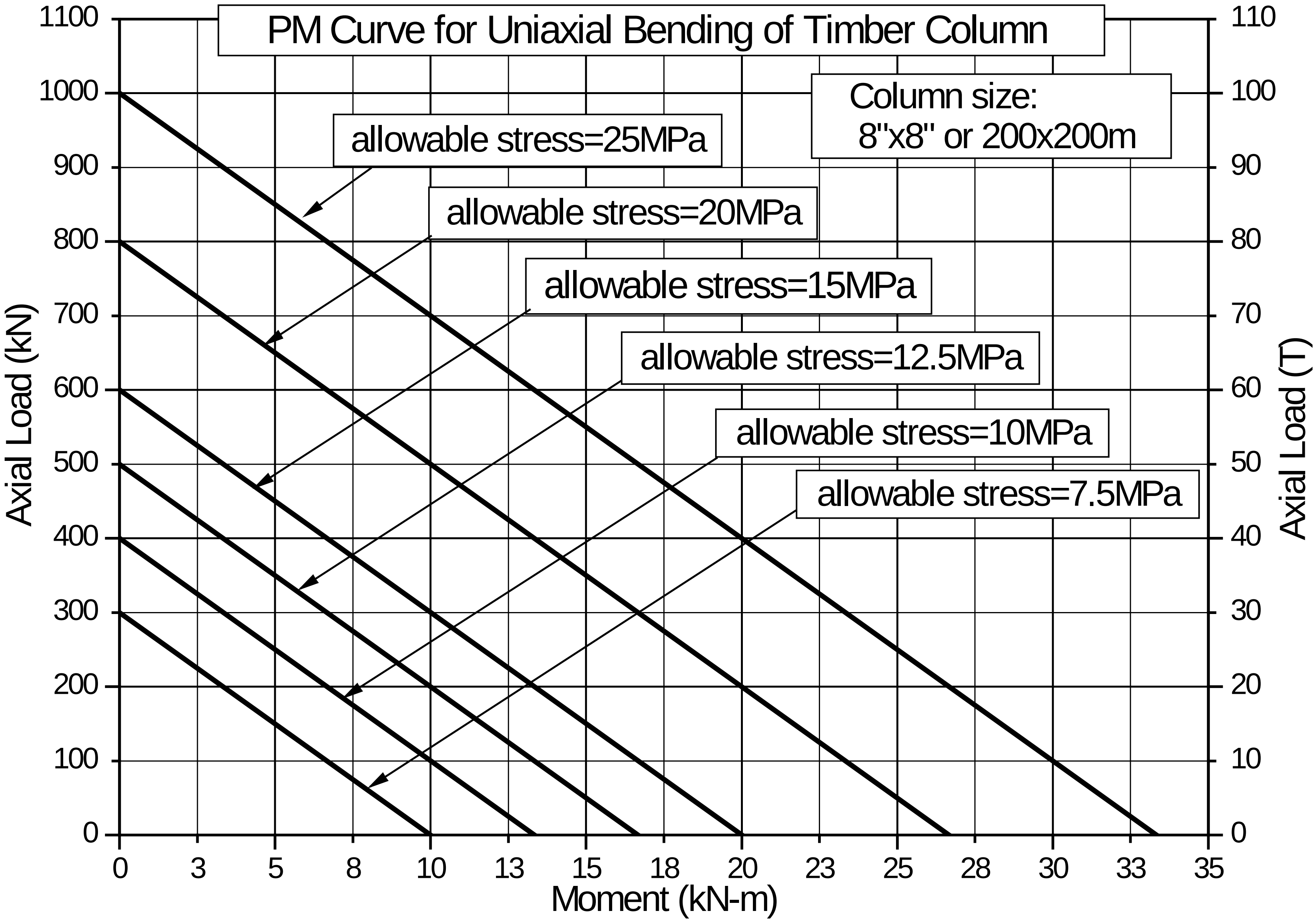


Figure 22: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 200x 200 mm)

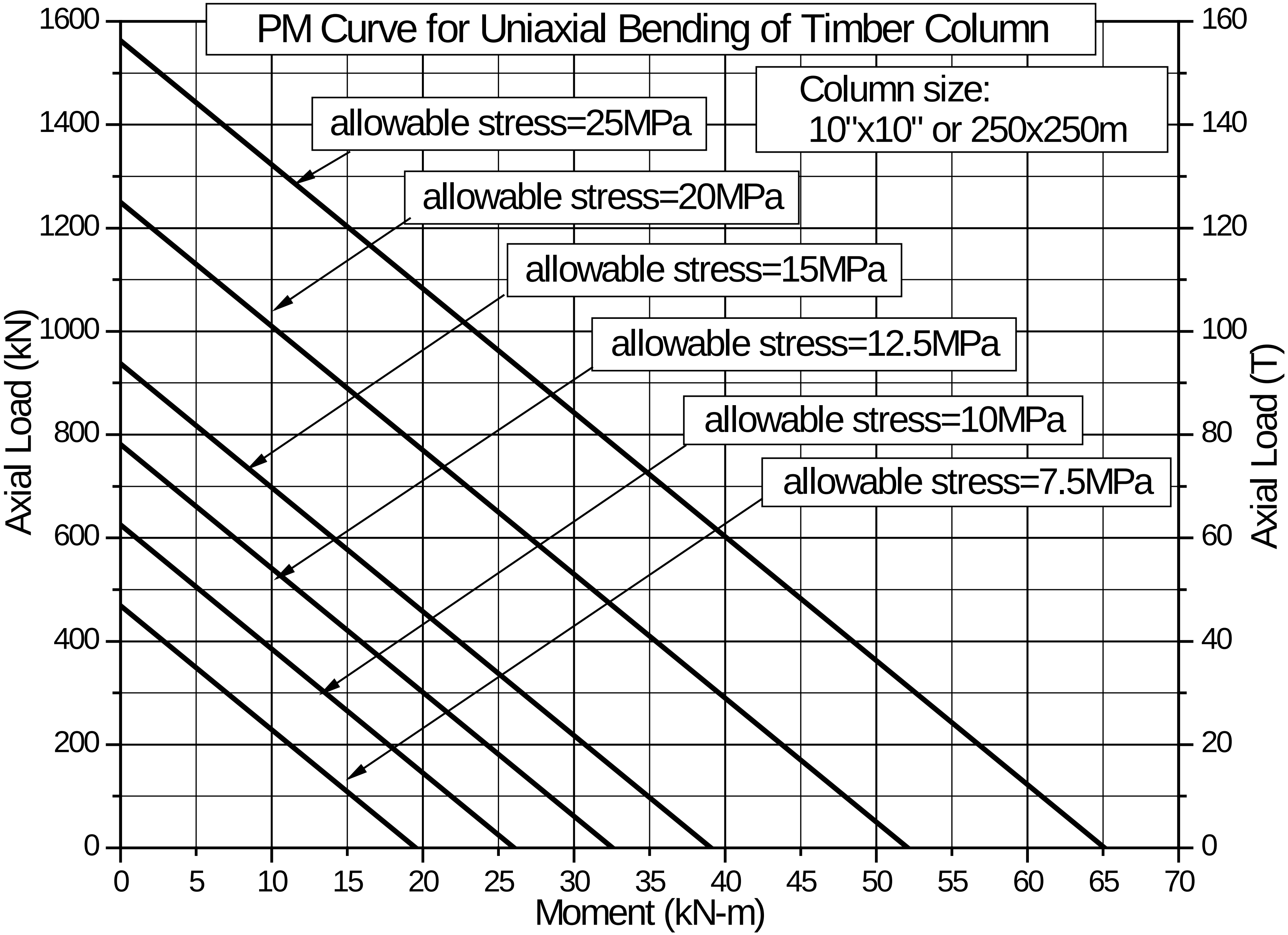


Figure 23: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 250x 250 mm)

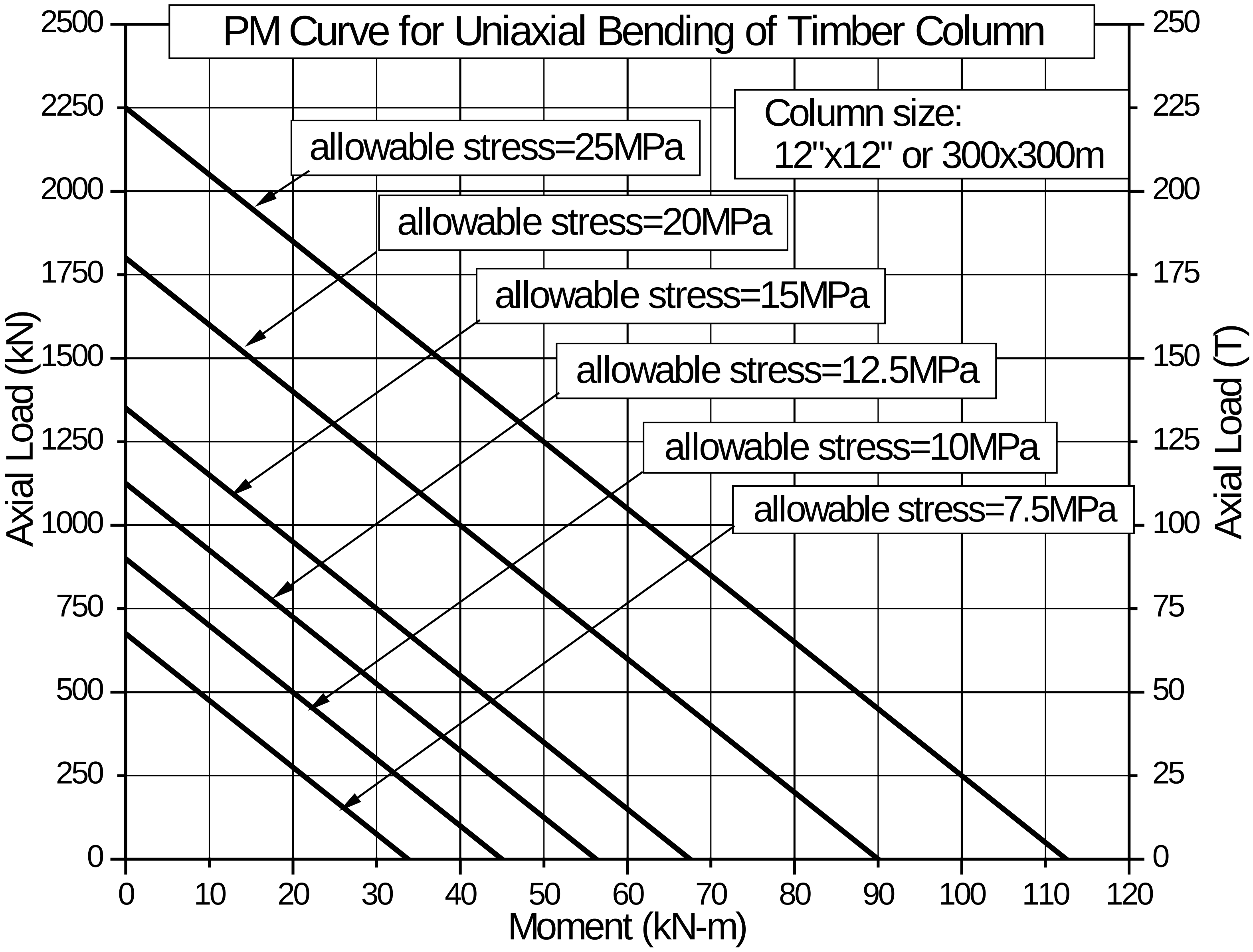


Figure 24: PM curve for Uniaxial Bending of Timber Column about Major Axis (Column size: 300x 300 mm)

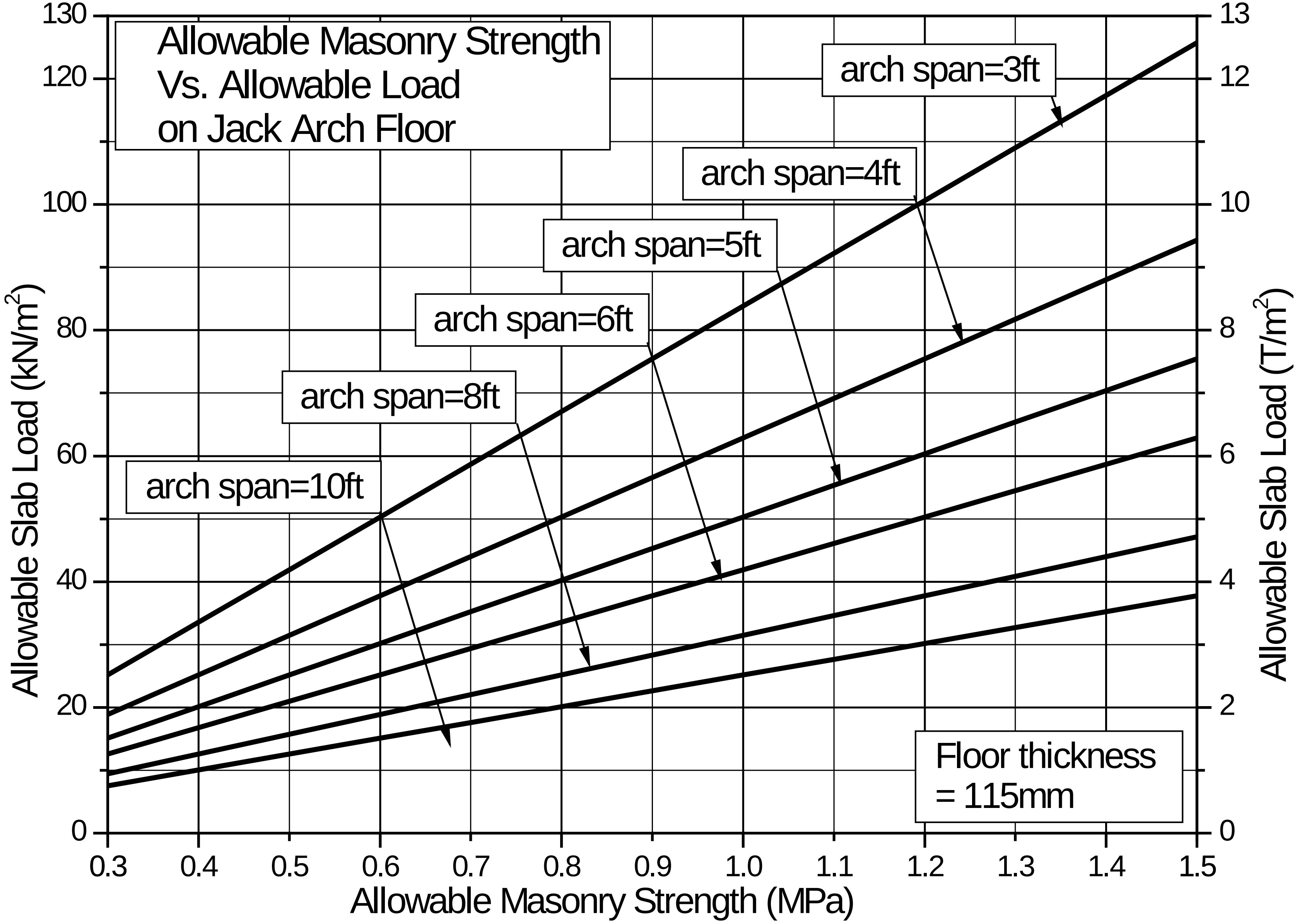


Figure 25: Allowable Masonry Strength vs. Allowable Load on Jack Arch Floor (Floor Thickness: 115mm)

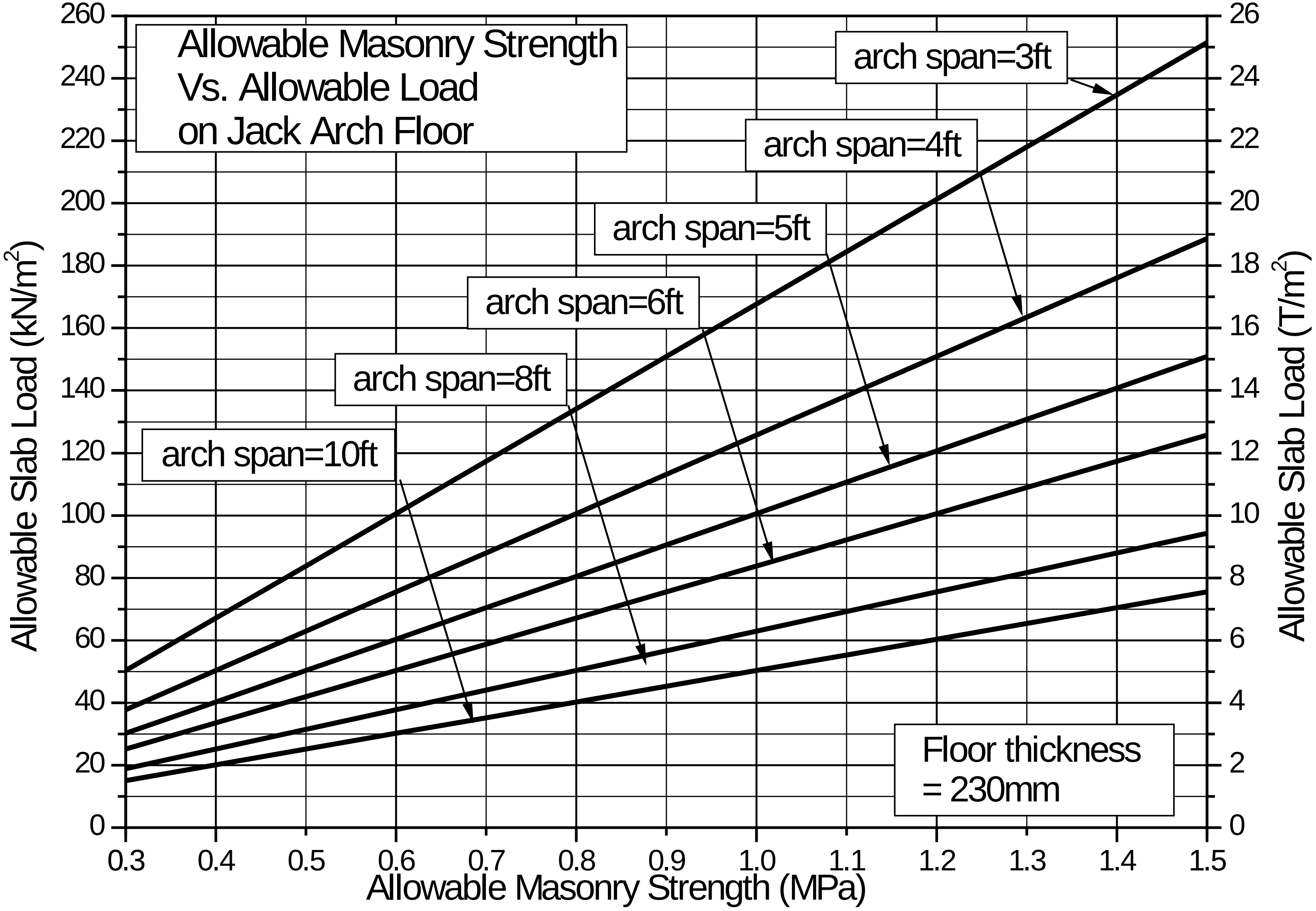


Figure 26: Allowable Masonry Strength vs. Allowable Load on Jack Arch Floor (Floor Thickness: 230mm)

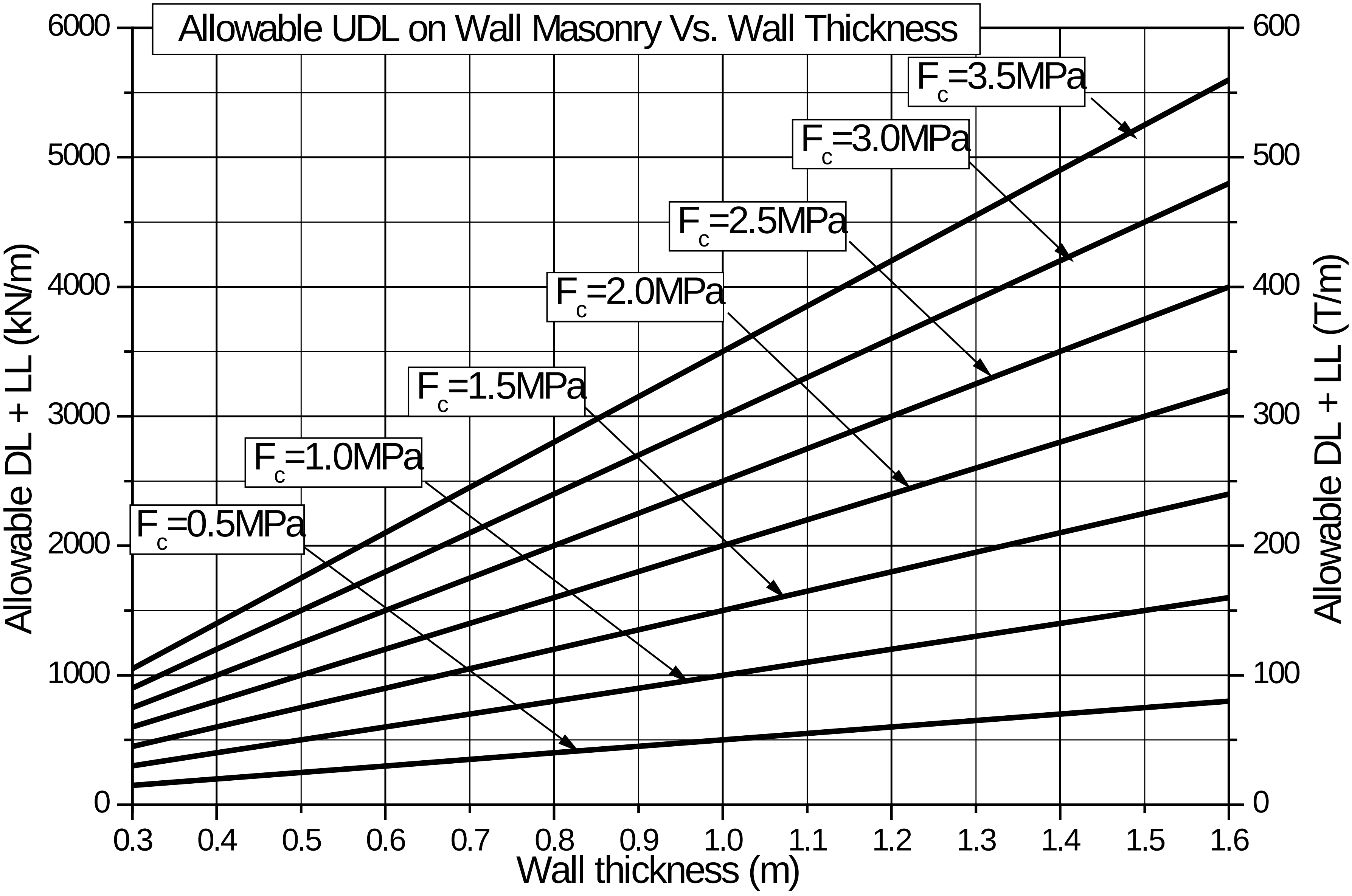


Figure 27: Allowable UDL on Masonry Wall vs. Wall Thickness

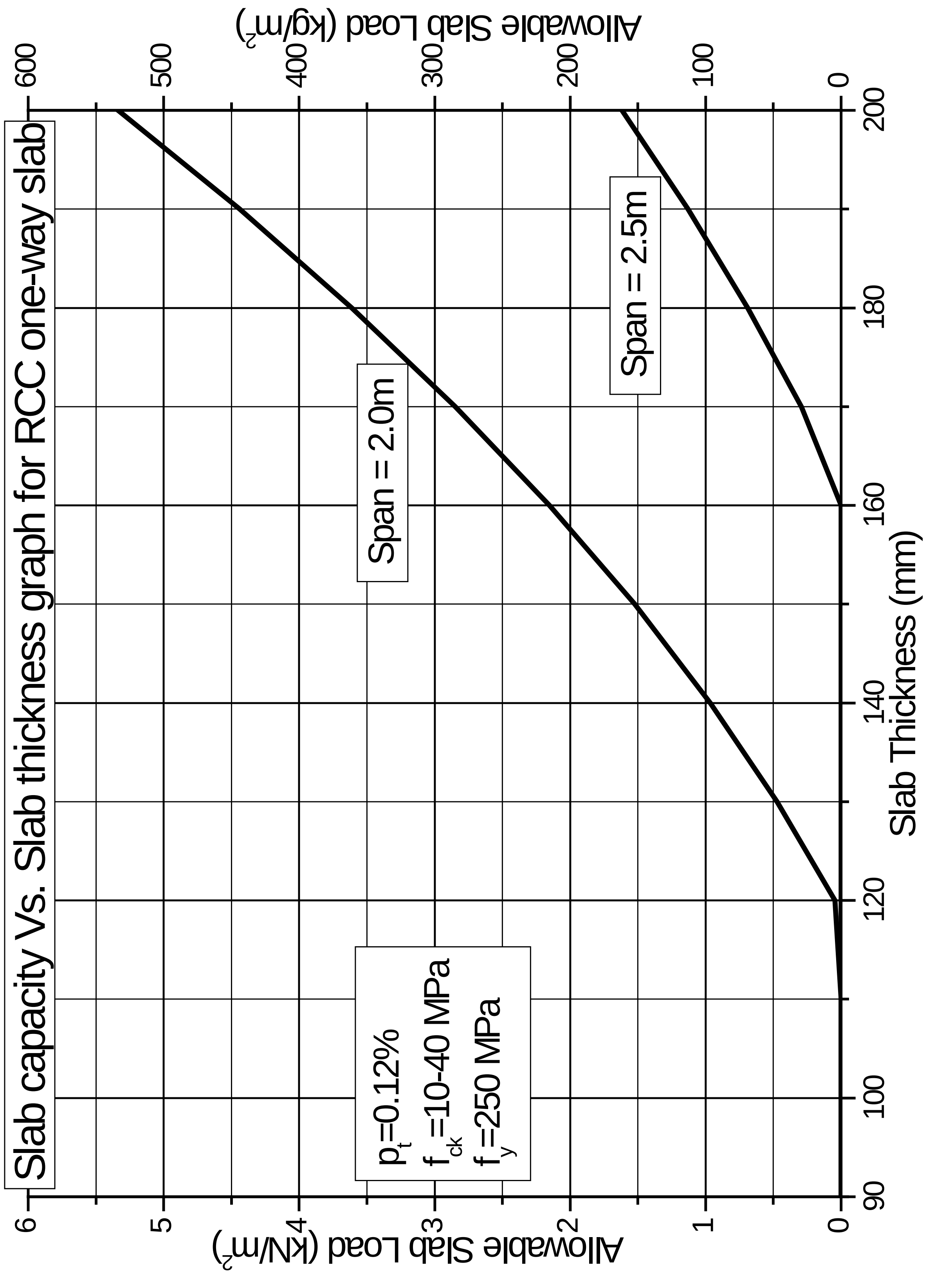


Figure 28: Slab capacity vs. slab thickness graph for RCC One-Way Slab (reinforcement = 0.12%, f_y = 250 MPa)

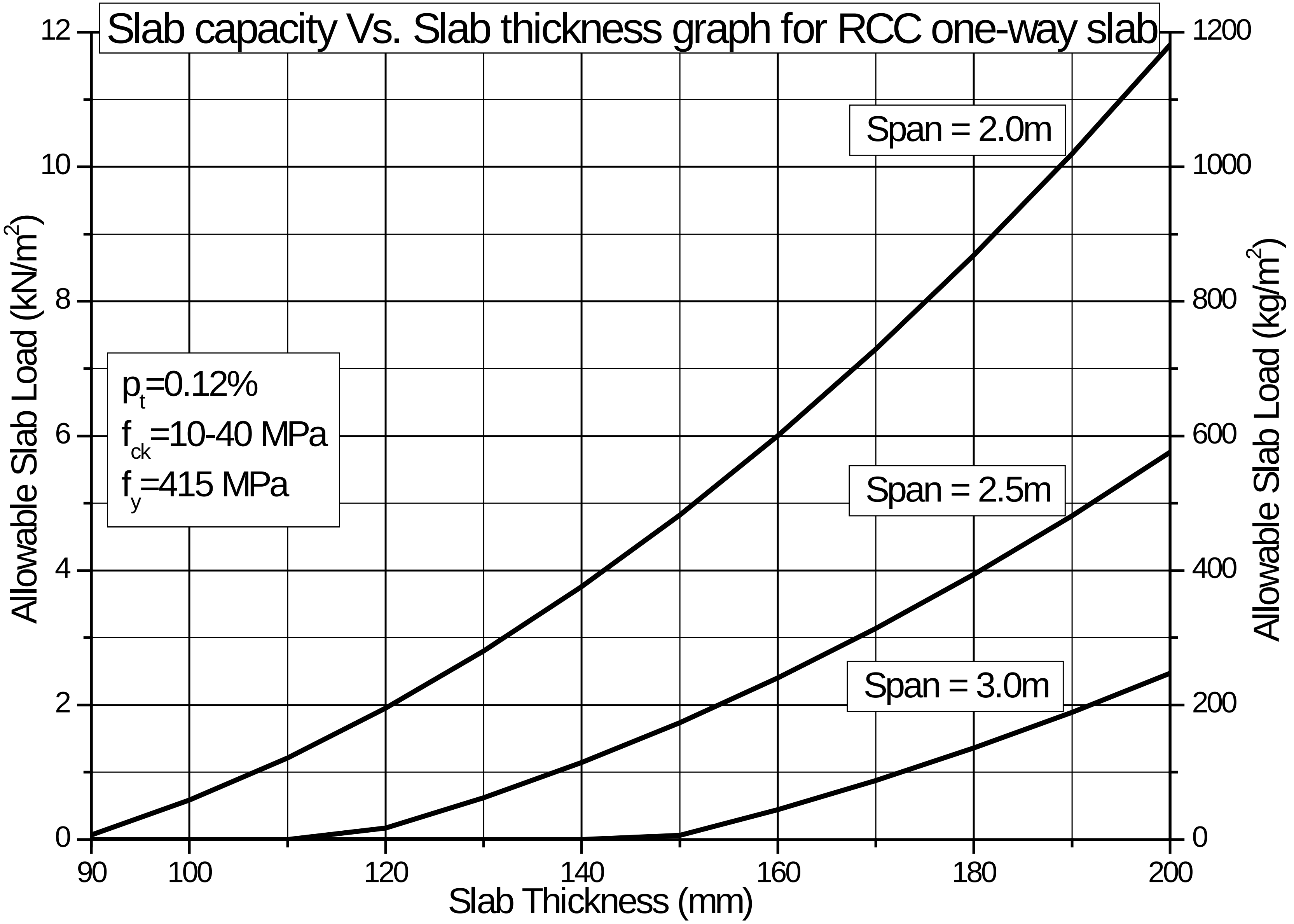


Figure 29: Slab capacity vs. slab thickness graph for RCC One-Way Slab (reinforcement = 0.12%, f_y = 415 MPa)

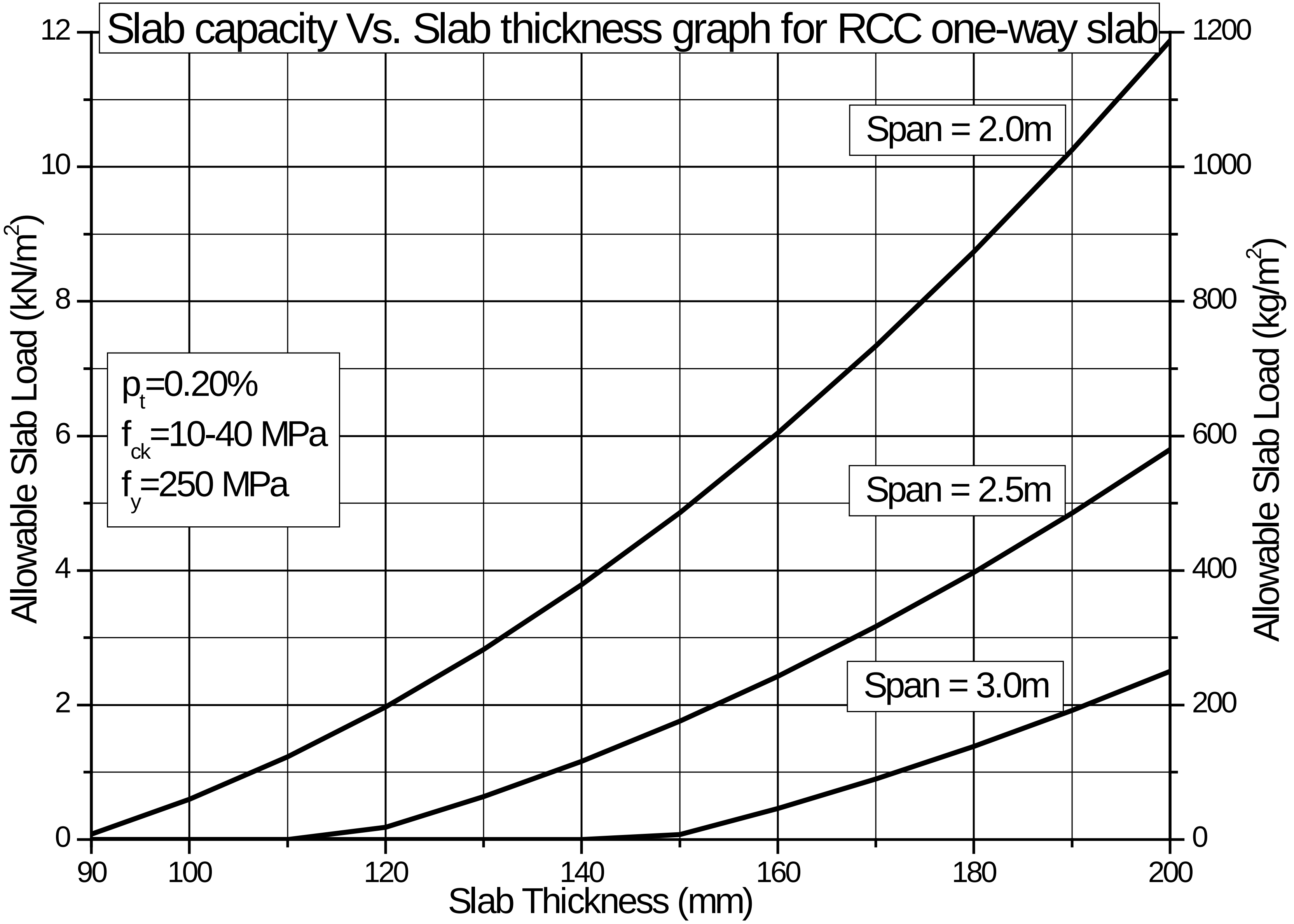


Figure 30: Slab capacity vs. slab thickness graph for RCC One-Way Slab (reinforcement = 0.20%, f_y = 250 MPa)

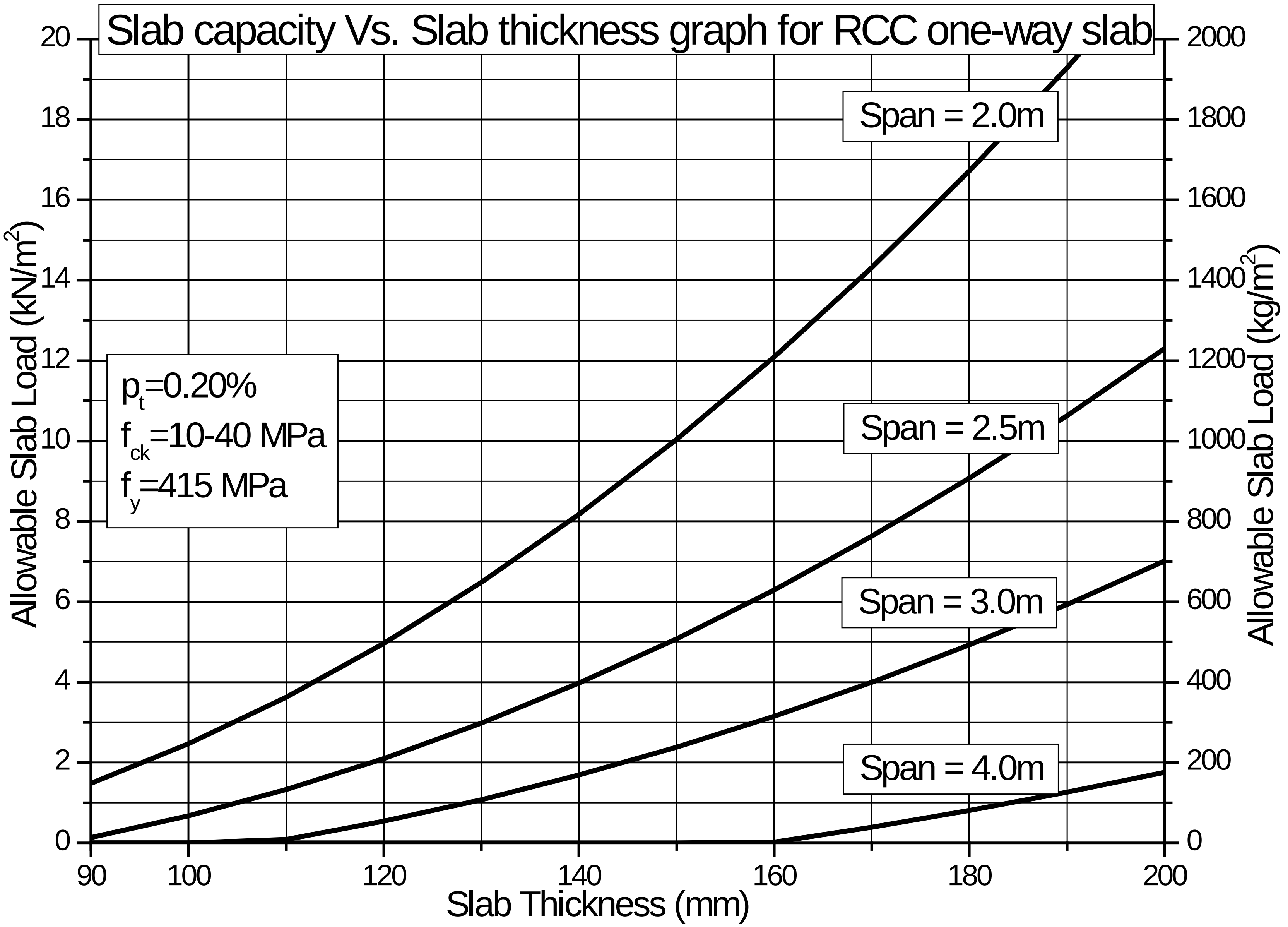


Figure 31: Slab capacity vs. slab thickness graph for RCC One-Way Slab (reinforcement = 0.20%, f_y = 415 MPa)

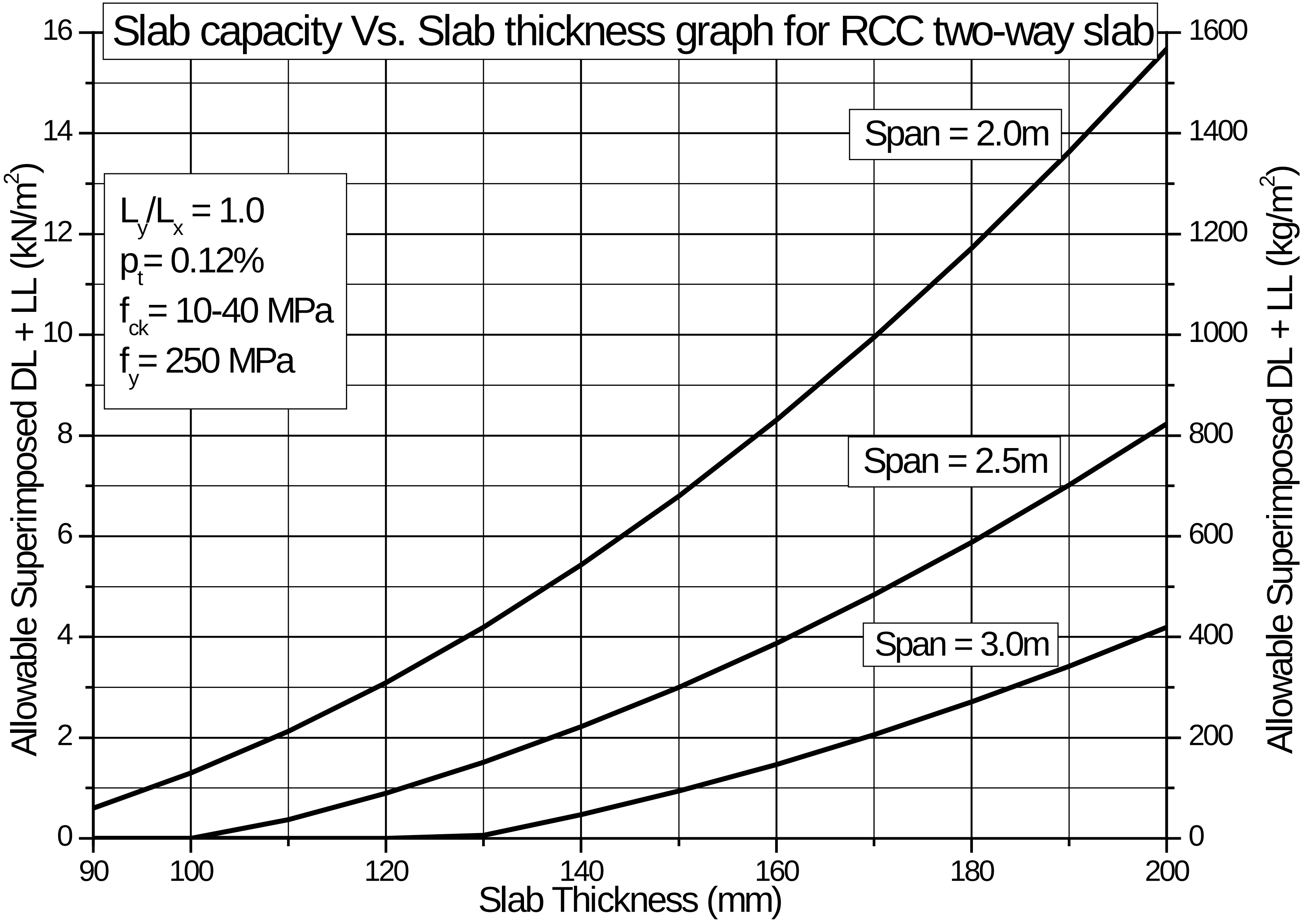


Figure 32: Slab capacity vs. slab thickness graph for RCC Two-Way Slab (reinforcement = 0.12%, f_y = 250 MPa)

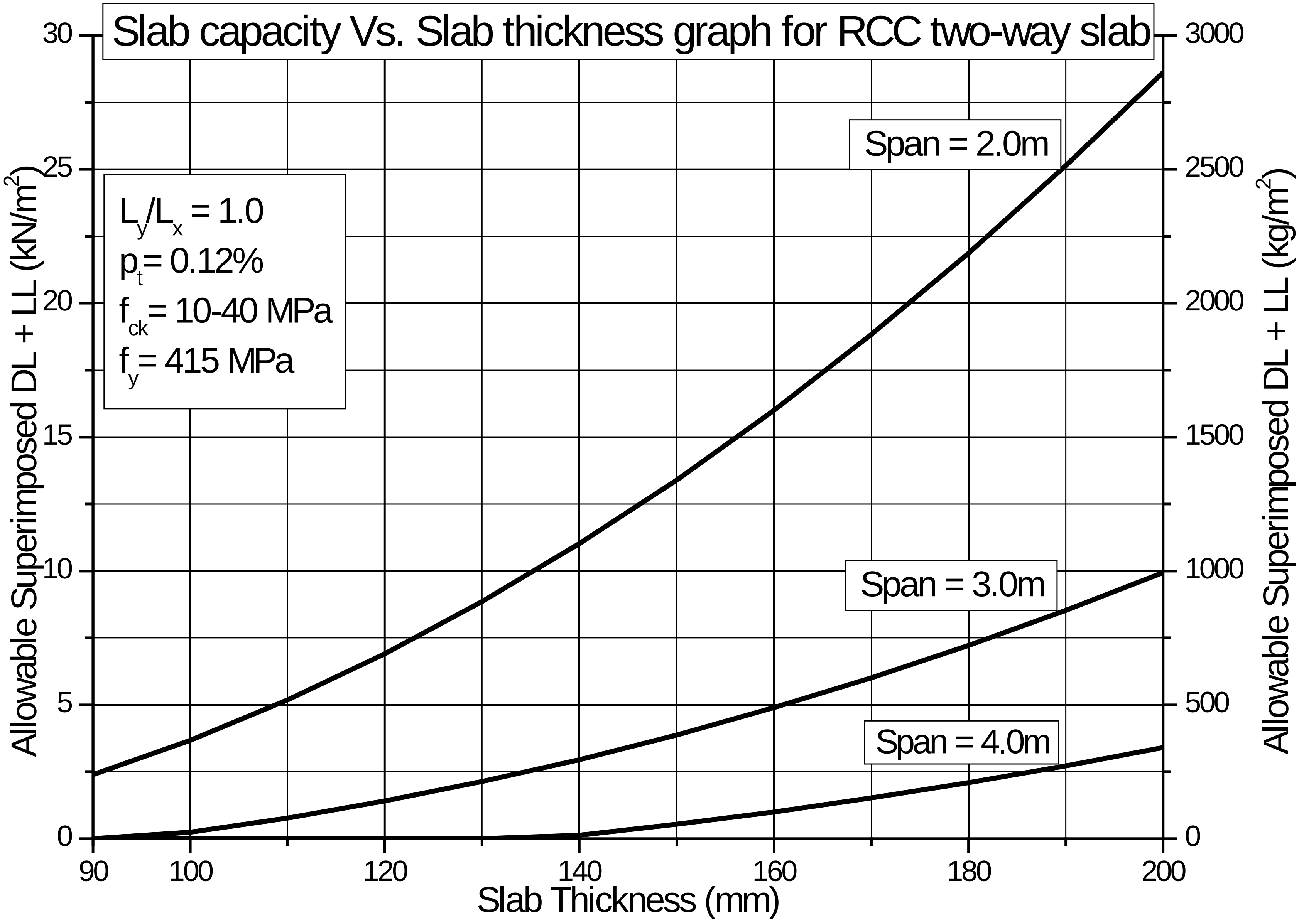


Figure 33: Slab capacity vs. Slab thickness graph for RCC Two-Way Slab (reinforcement = 0.12%, f_y = 415 MPa)

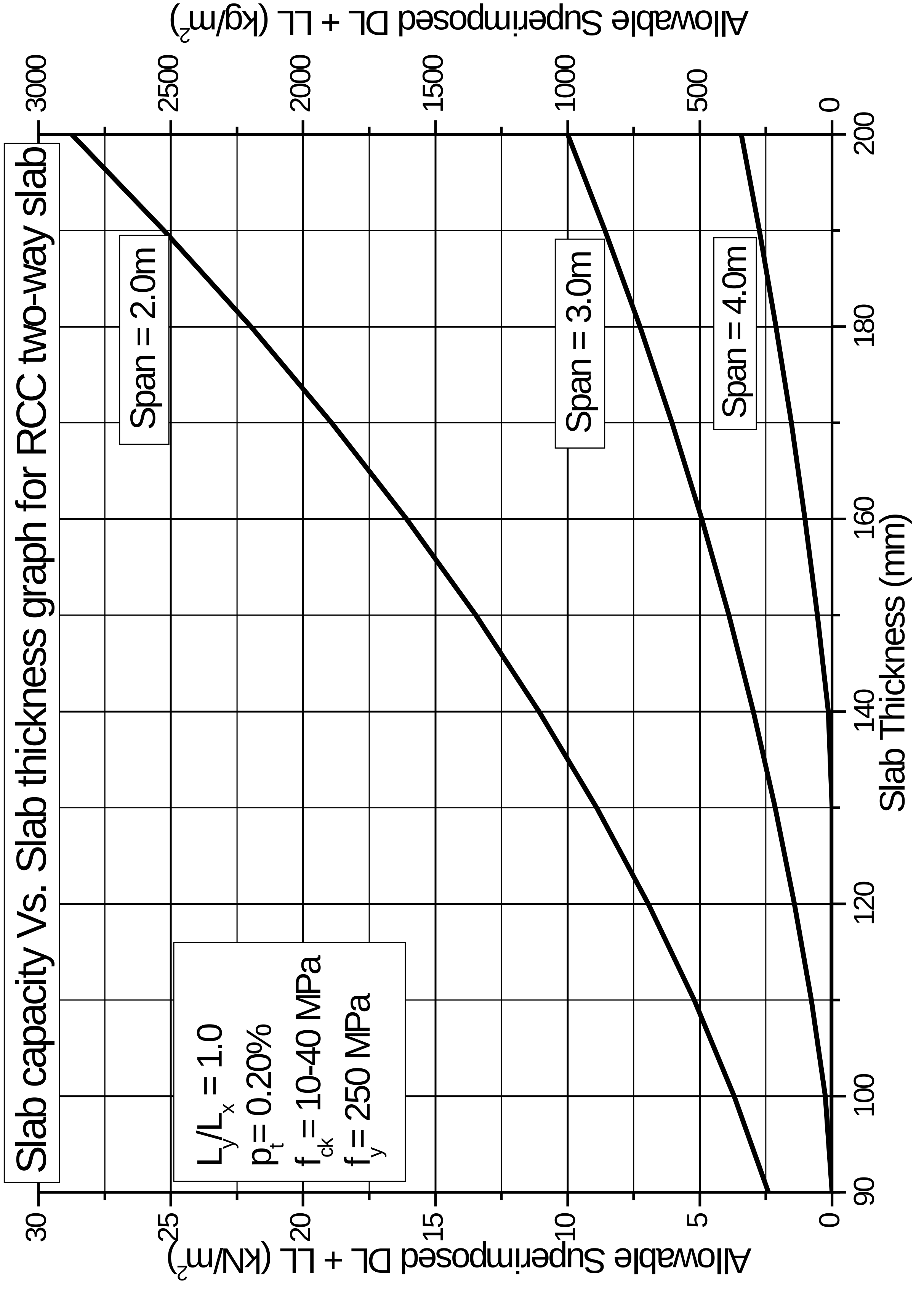


Figure 34: Slab capacity vs. Slab thickness graph for RCC Two-Way Slab (reinforcement = 0.20%, f_y = 250 MPa)

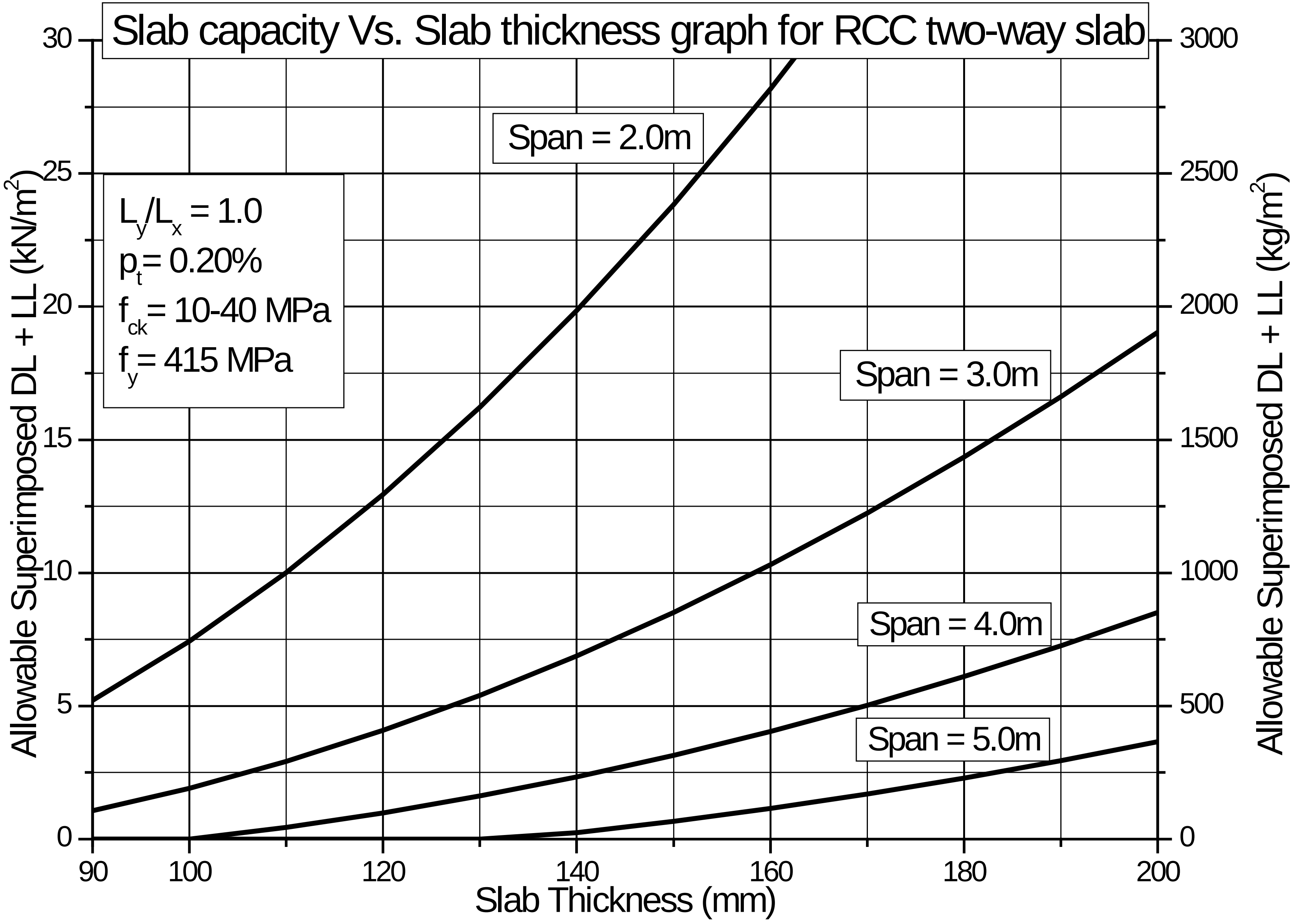


Figure 35: Slab capacity vs. Slab thickness graph for RCC Two-Way Slab (reinforcement = 0.20%, f_y = 415 MPa)

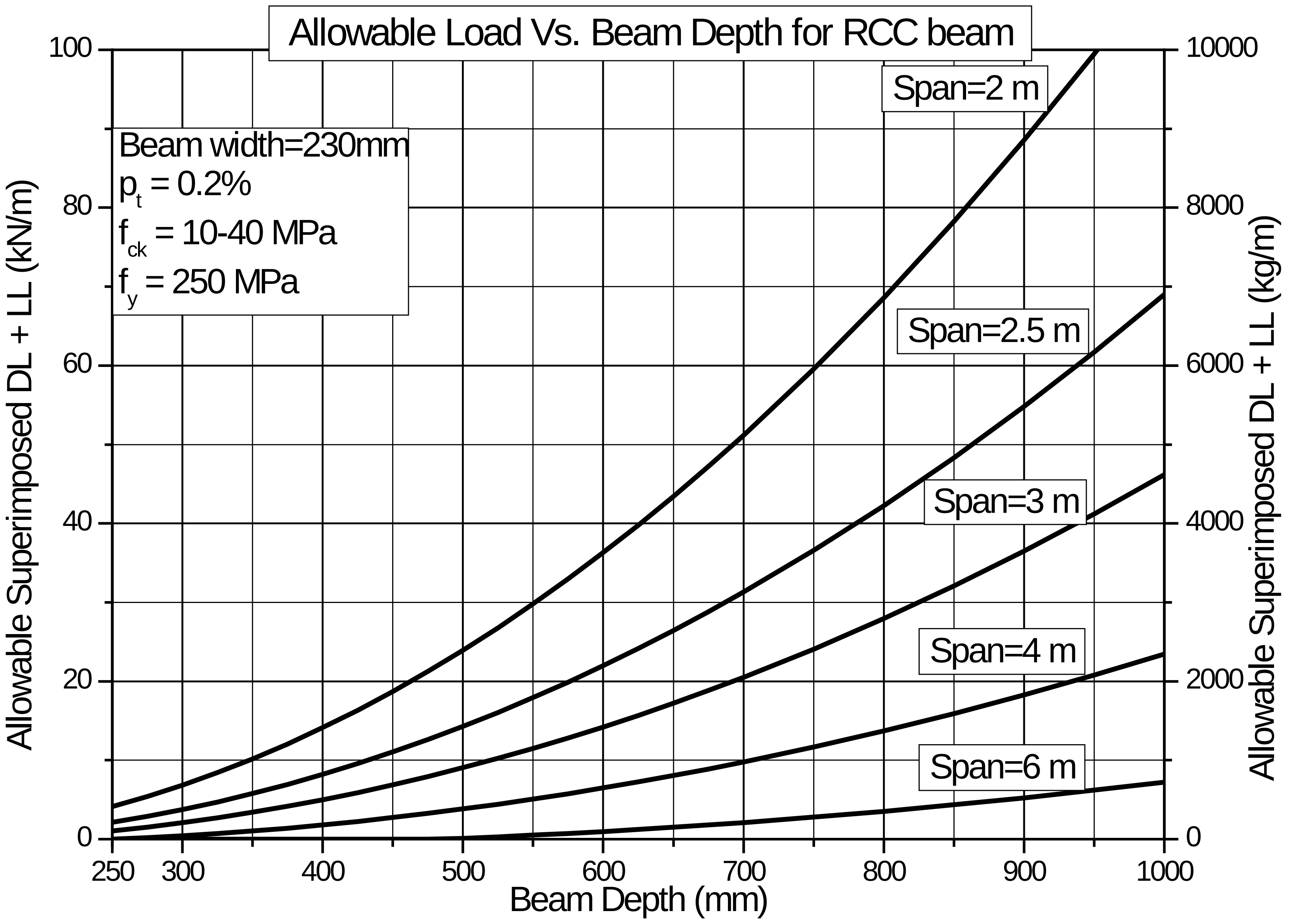


Figure 36: Allowable Load vs. Beam Depth for RCC beam

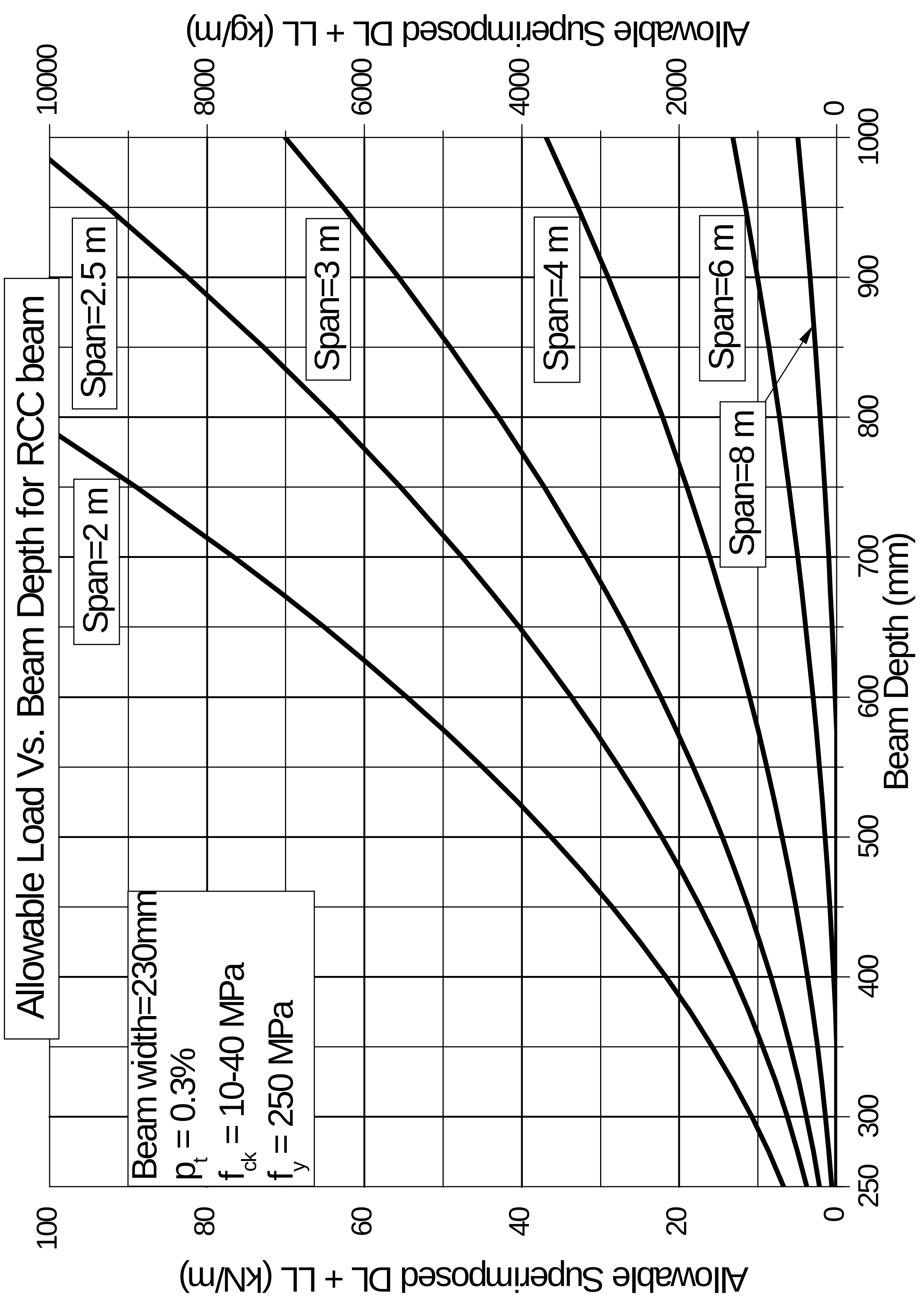


Figure 37: Allowable Load vs. Beam Depth for RCC beam

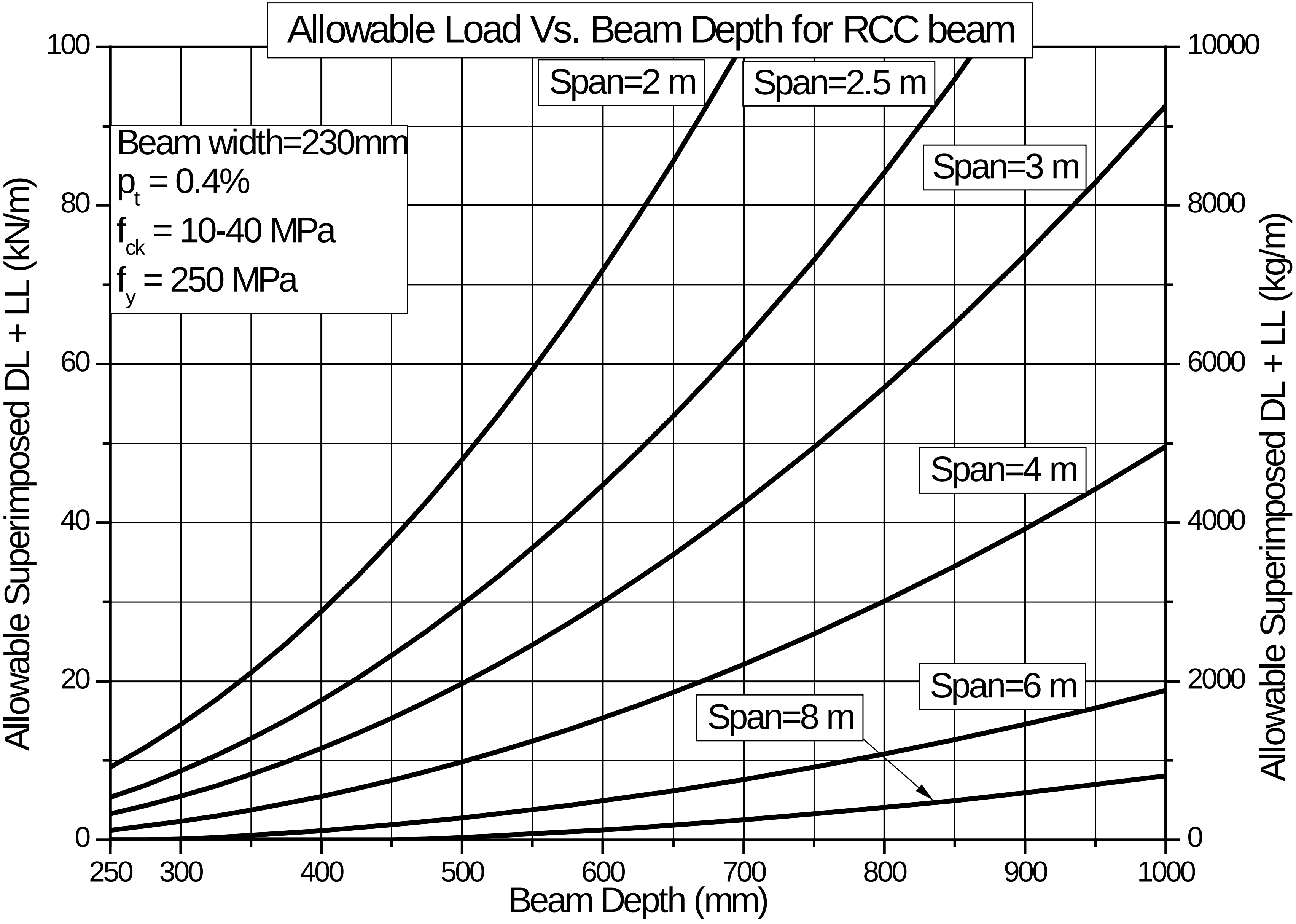


Figure 38: Allowable Load vs. Beam Depth for RCC beam

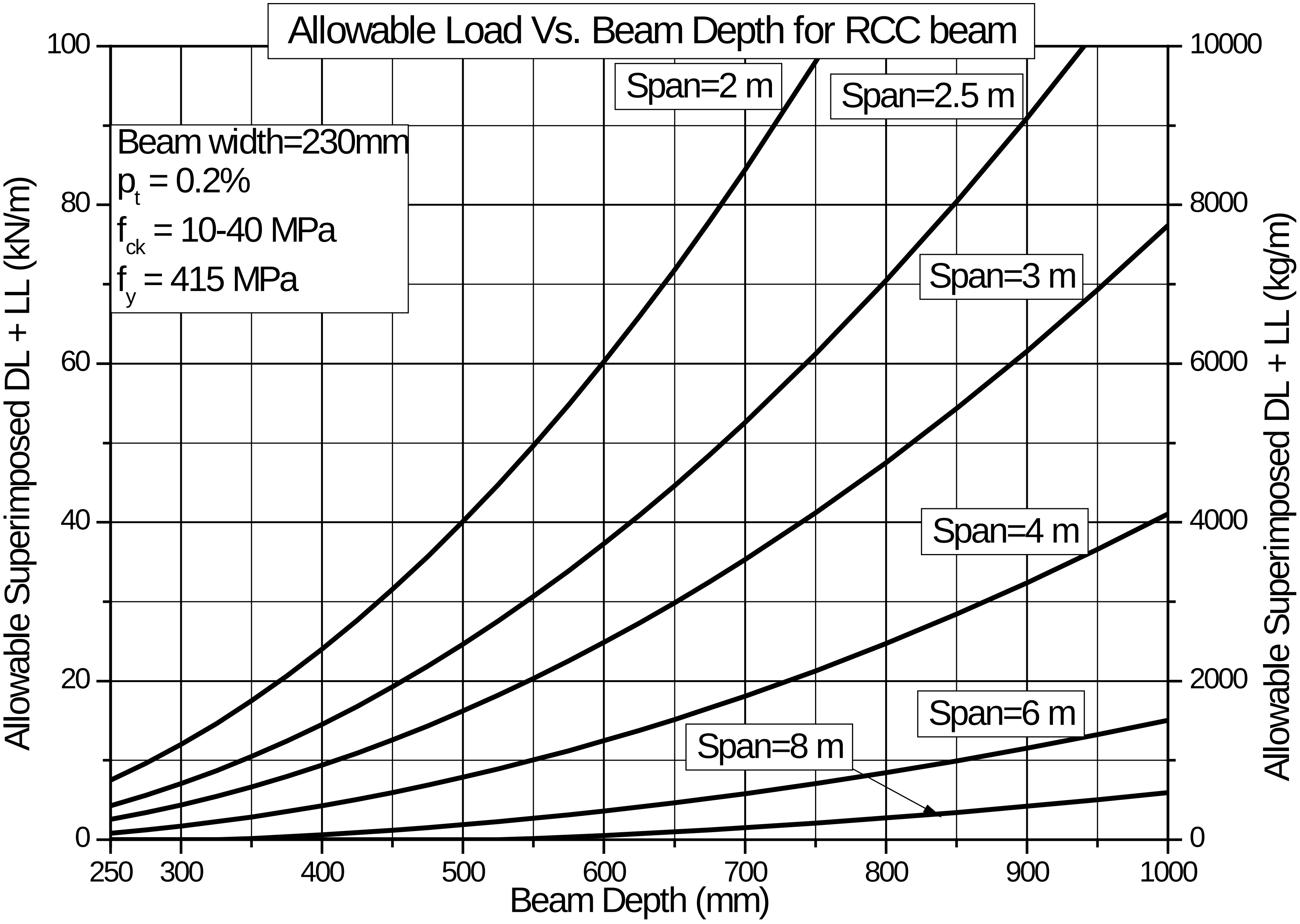


Figure 39: Allowable Load vs. Beam Depth for RCC beam

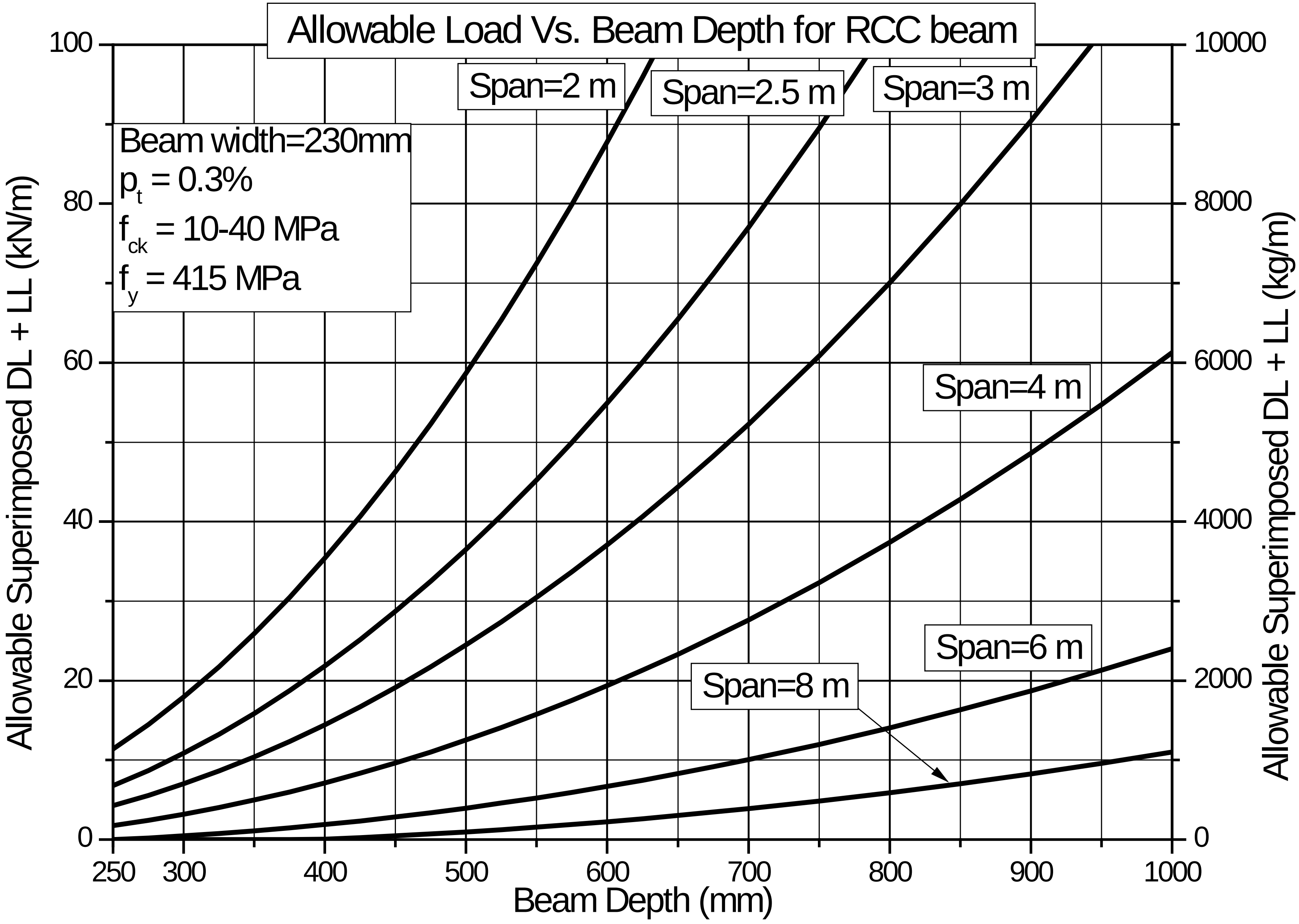


Figure 40: Allowable Load vs. Beam Depth for RCC beam

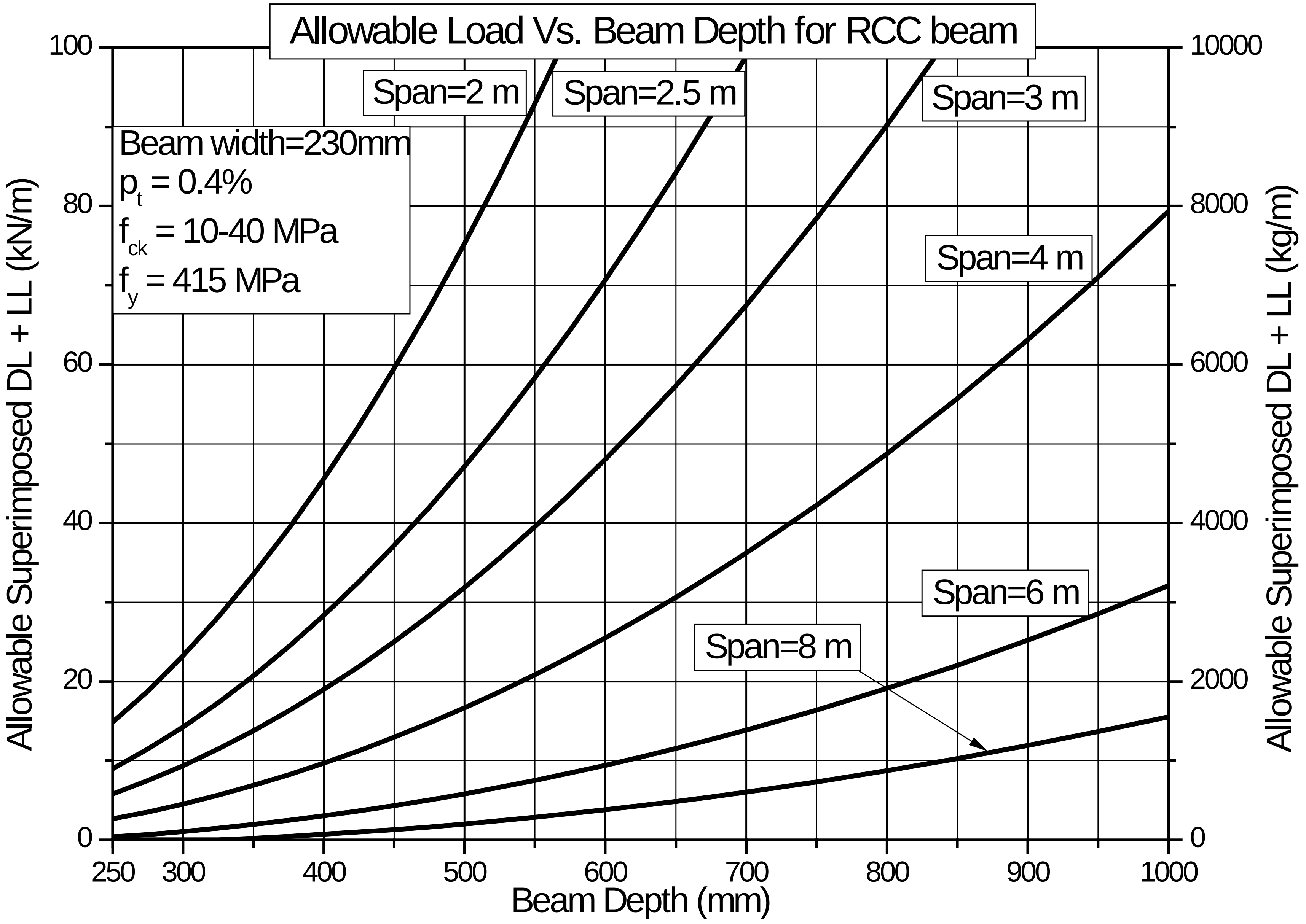


Figure 41: Allowable Load vs. Beam Depth for RCC beam

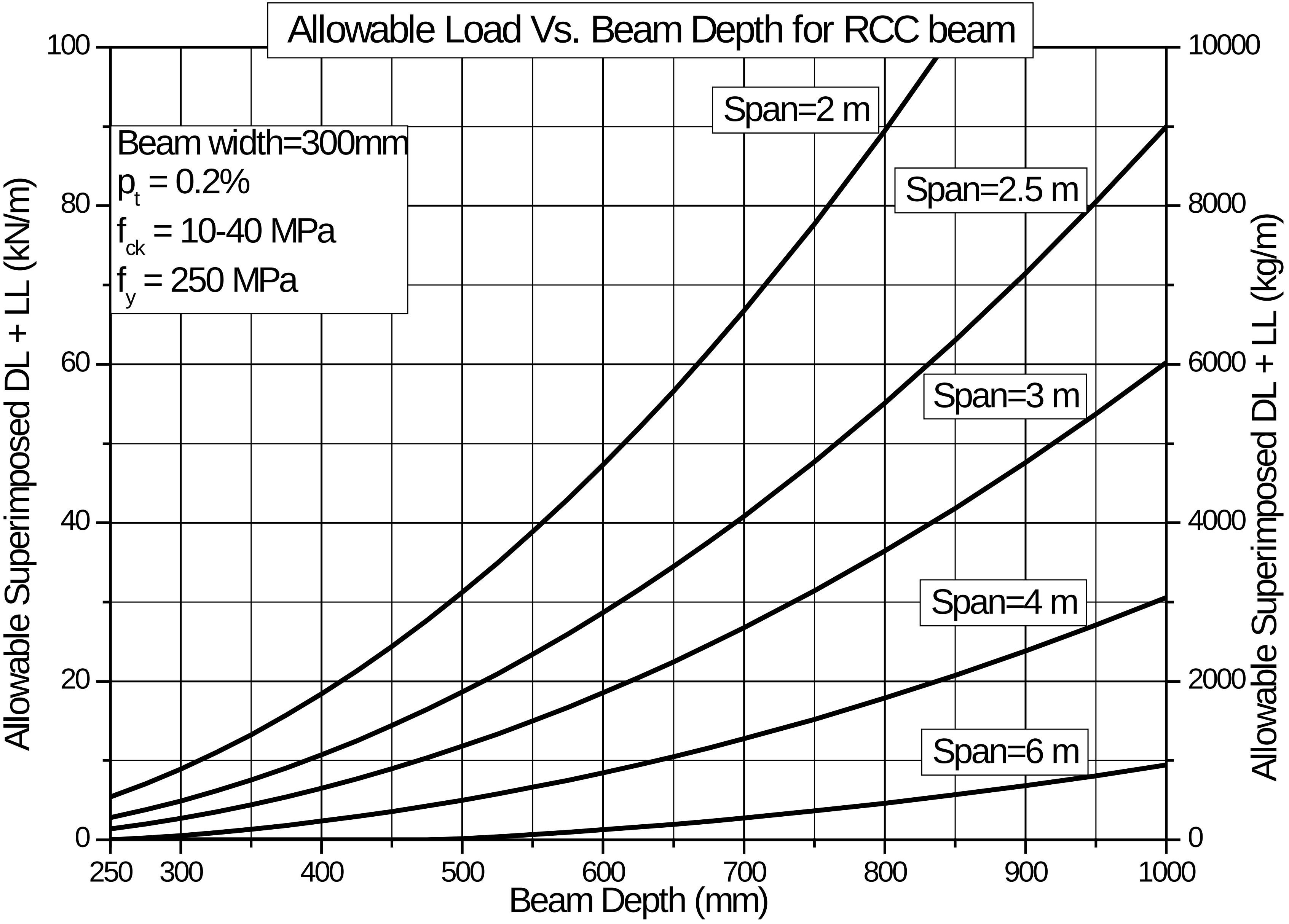


Figure 42: Allowable Load vs. Beam Depth for RCC beam

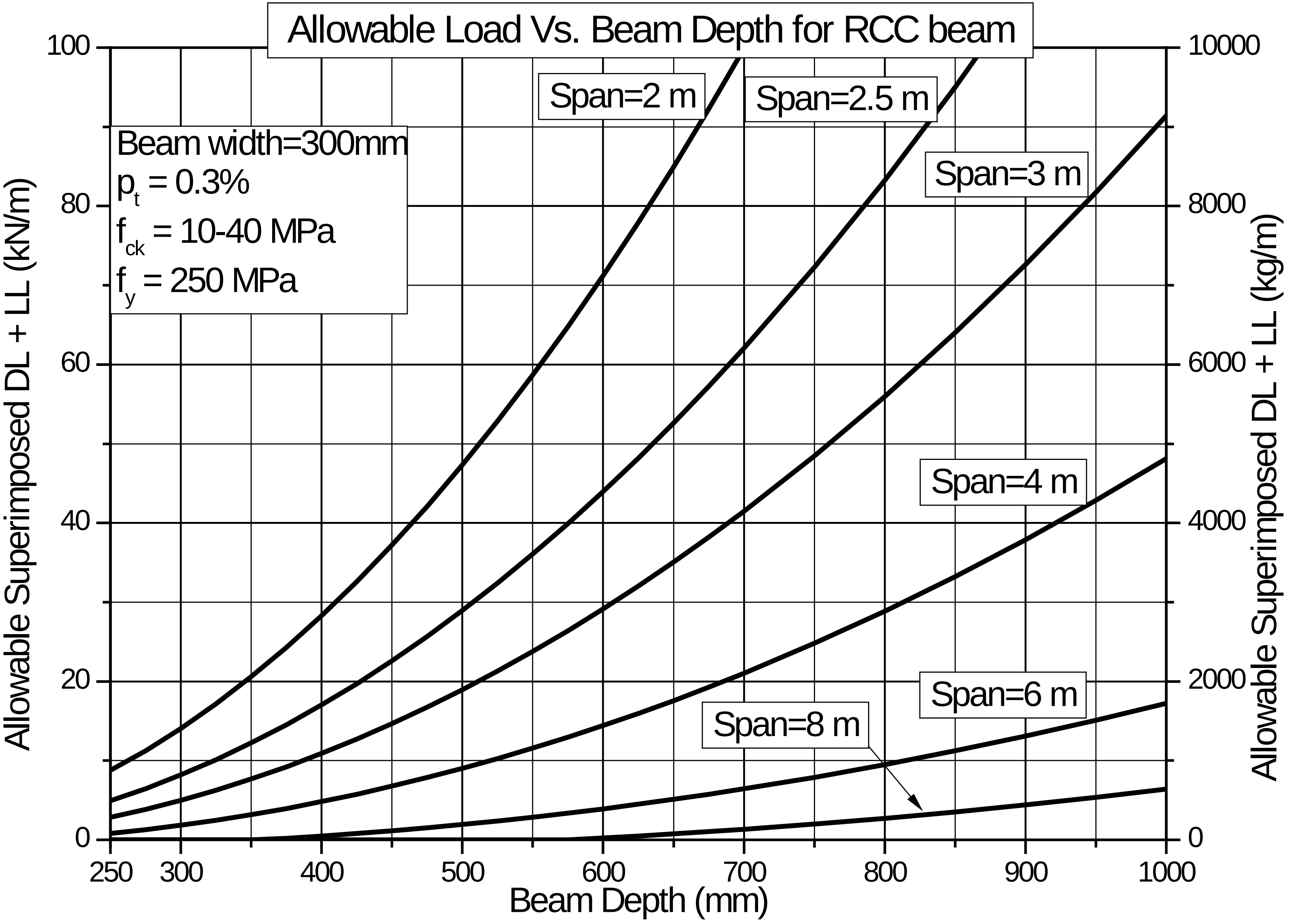


Figure 43: Allowable Load vs. Beam Depth for RCC beam

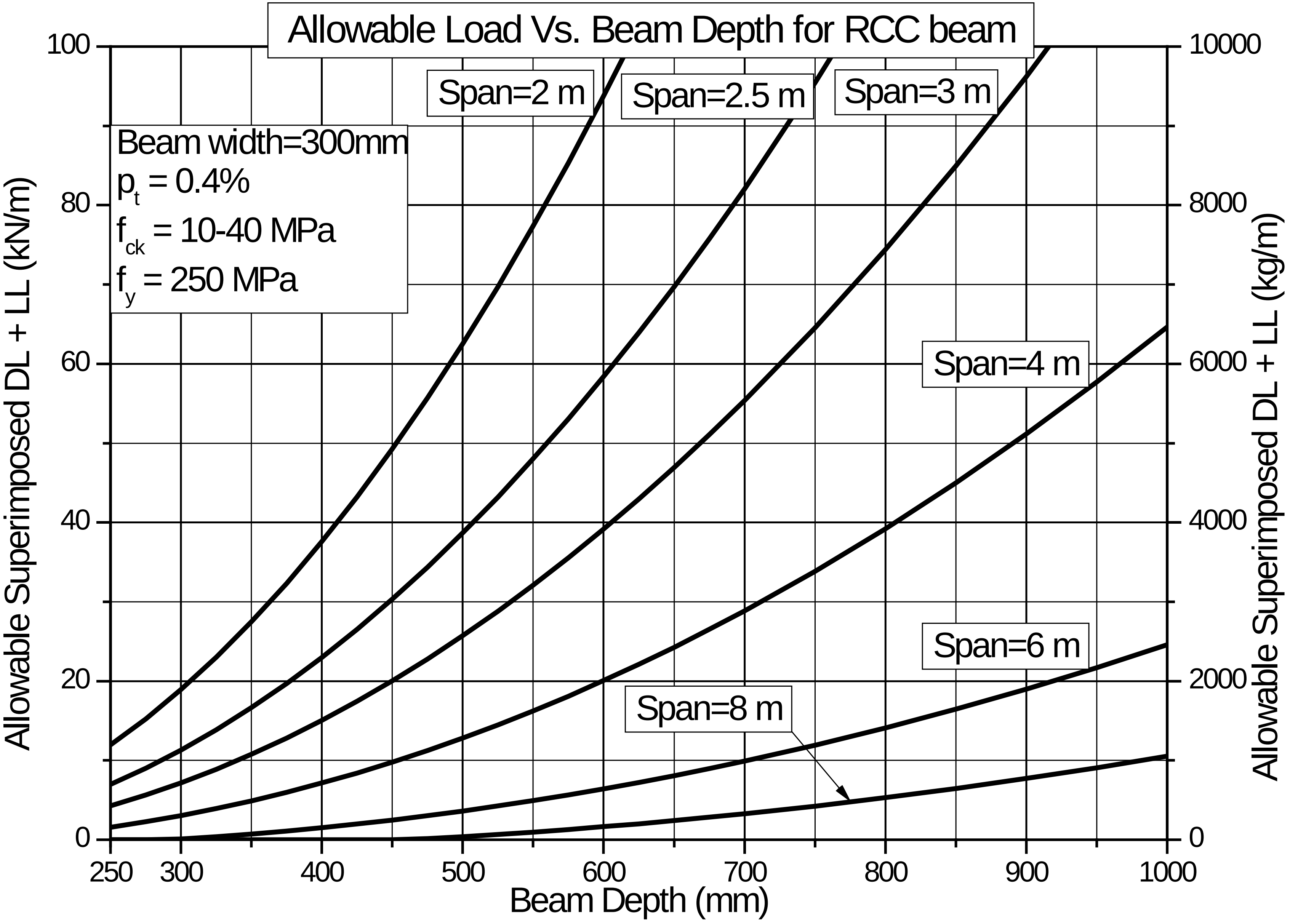


Figure 44: Allowable Load vs. Beam Depth for RCC beam

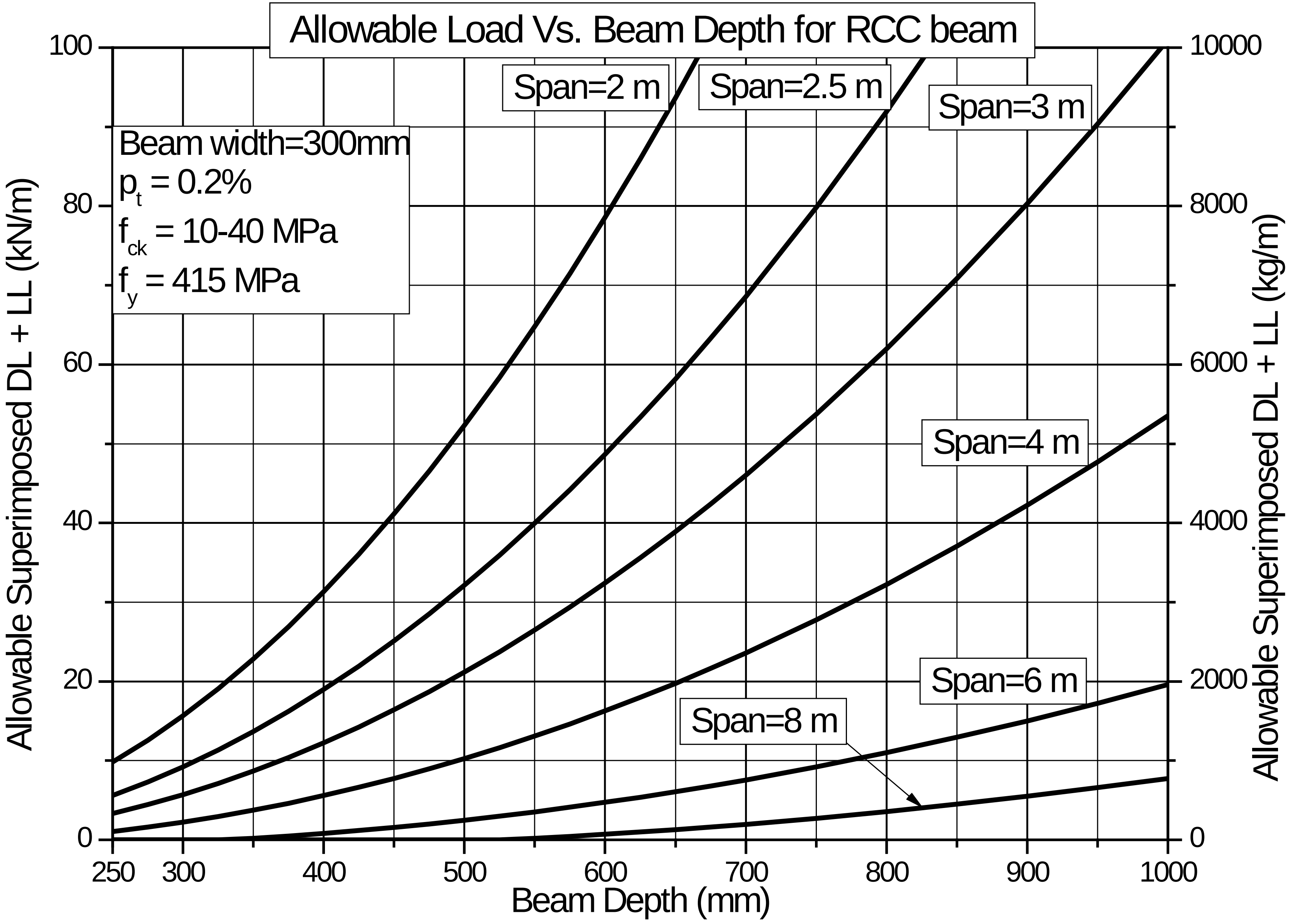


Figure 45: Allowable Load vs. Beam Depth for RCC beam

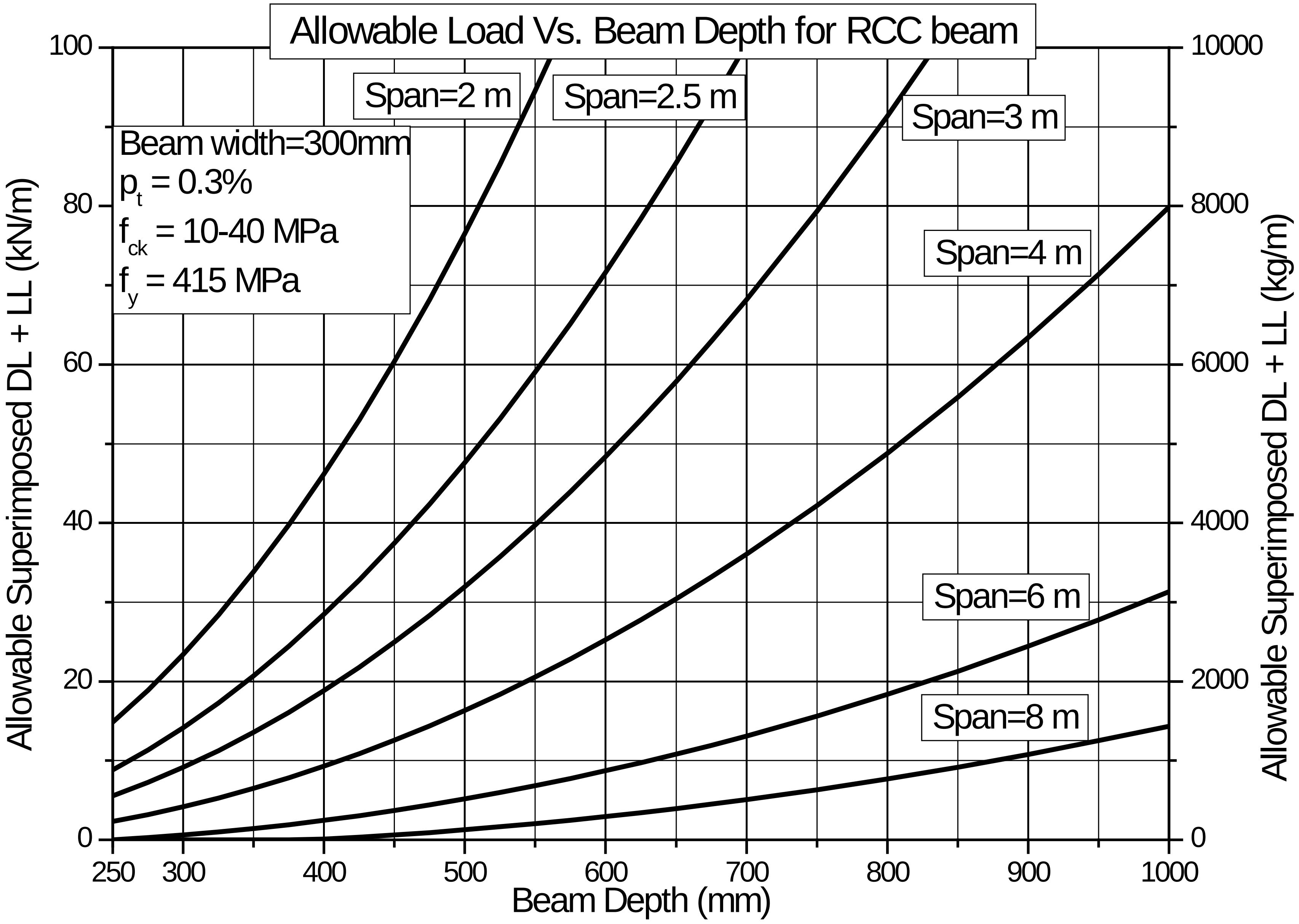


Figure 46: Allowable Load vs. Beam Depth for RCC beam

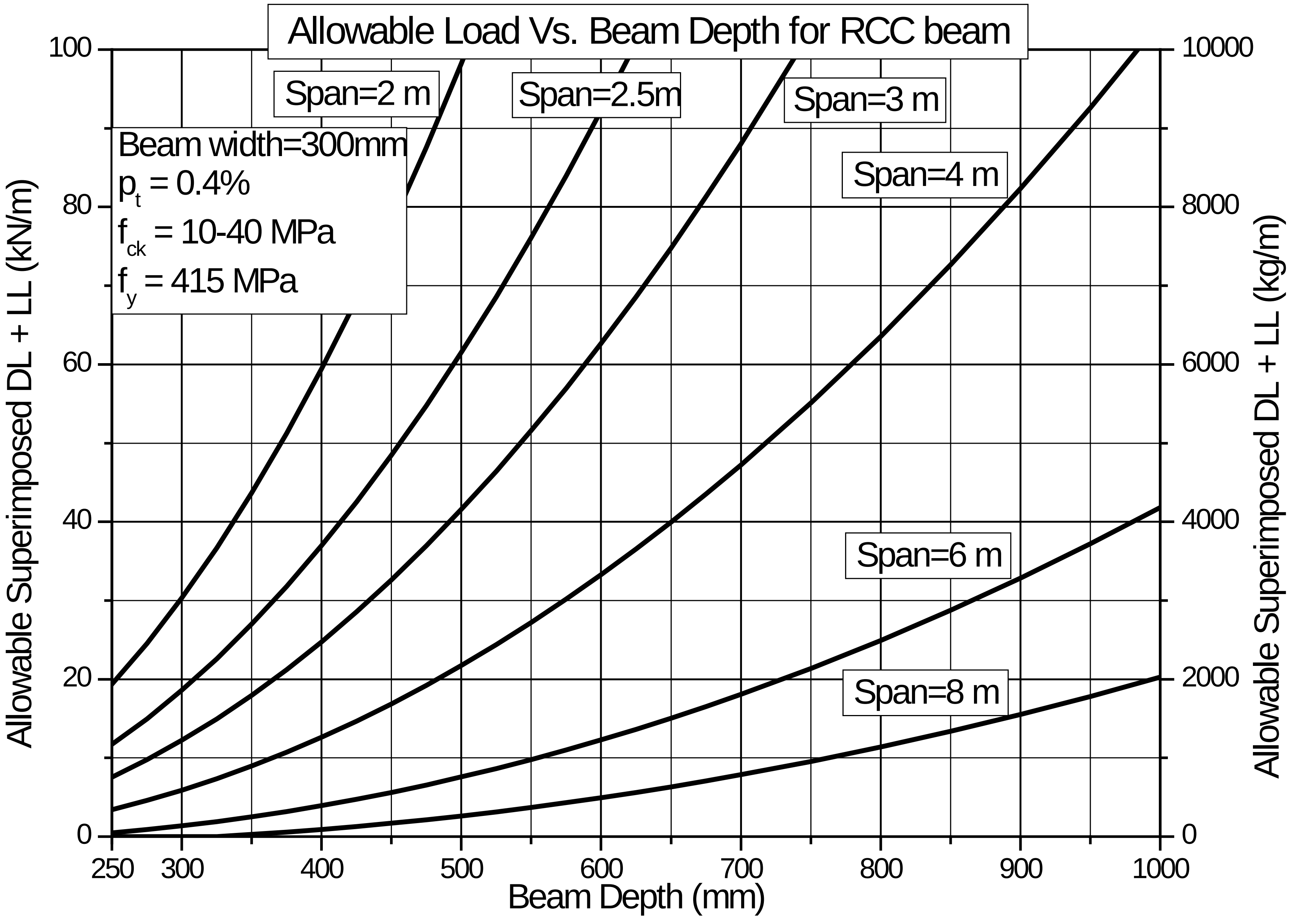


Figure 47: Allowable Load vs. Beam Depth for RCC beam

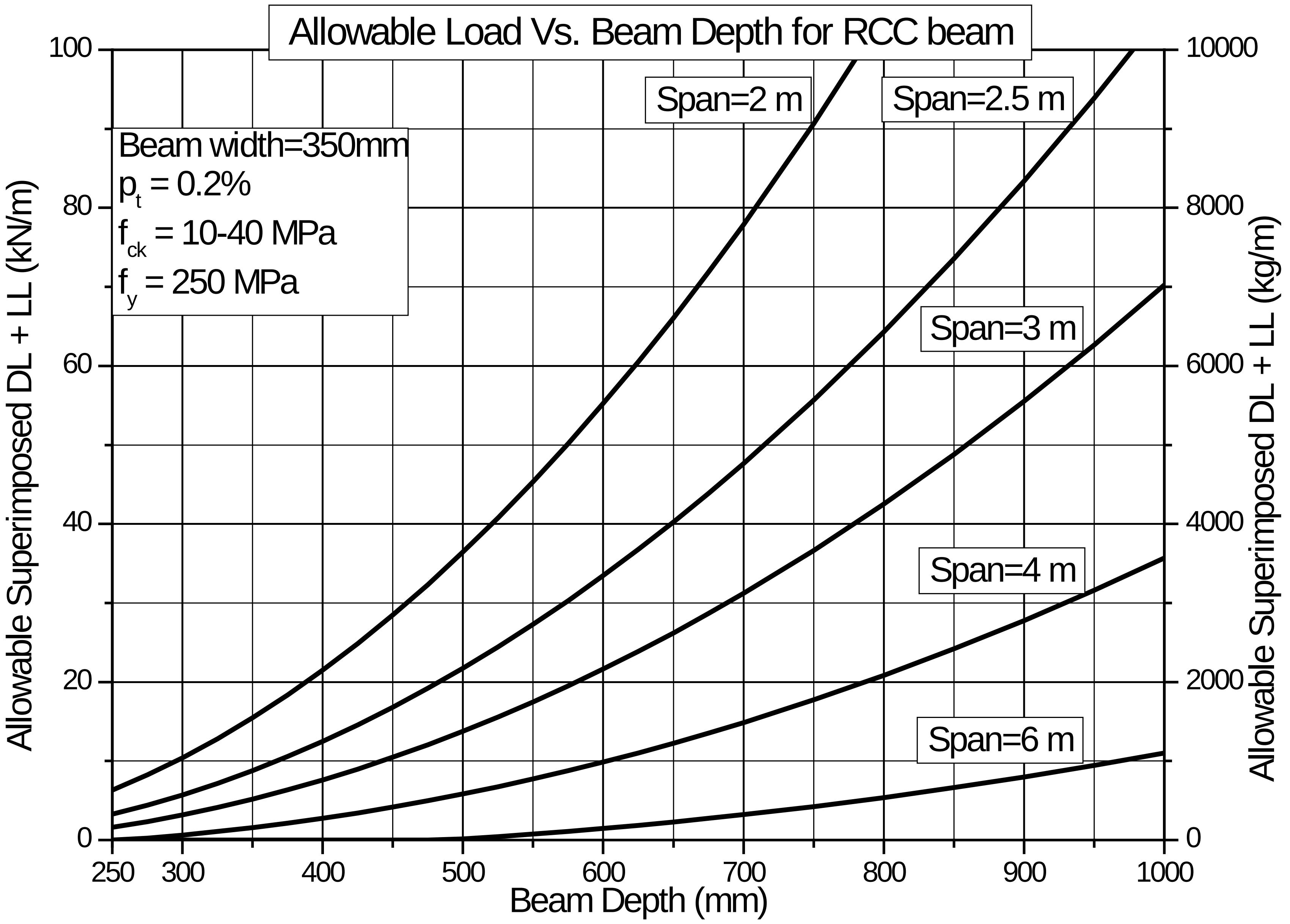


Figure 48: Allowable Load vs. Beam Depth for RCC beam

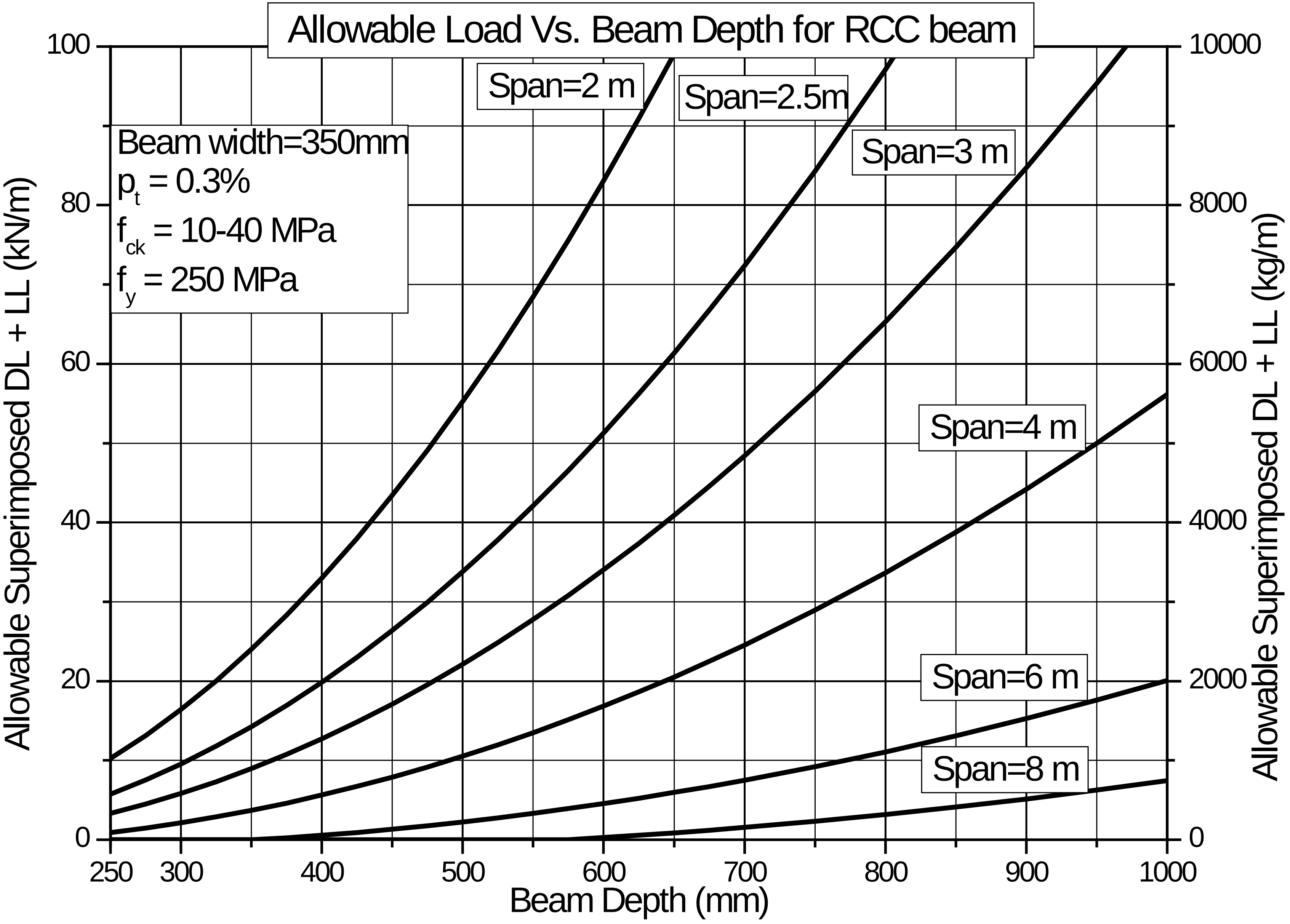


Figure 49: Allowable Load vs. Beam Depth for RCC beam

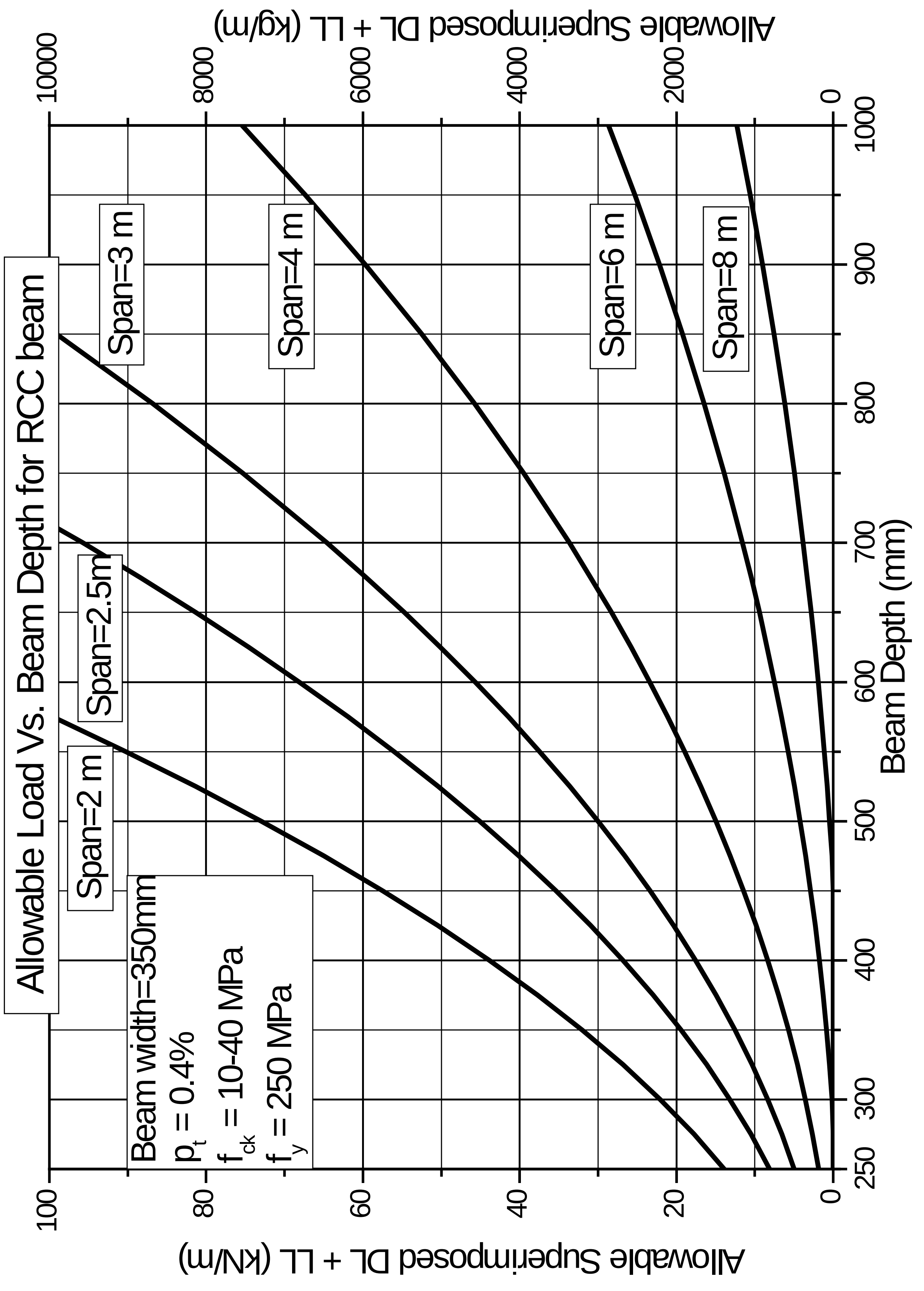


Figure 50: Allowable Load vs. Beam Depth for RCC beam

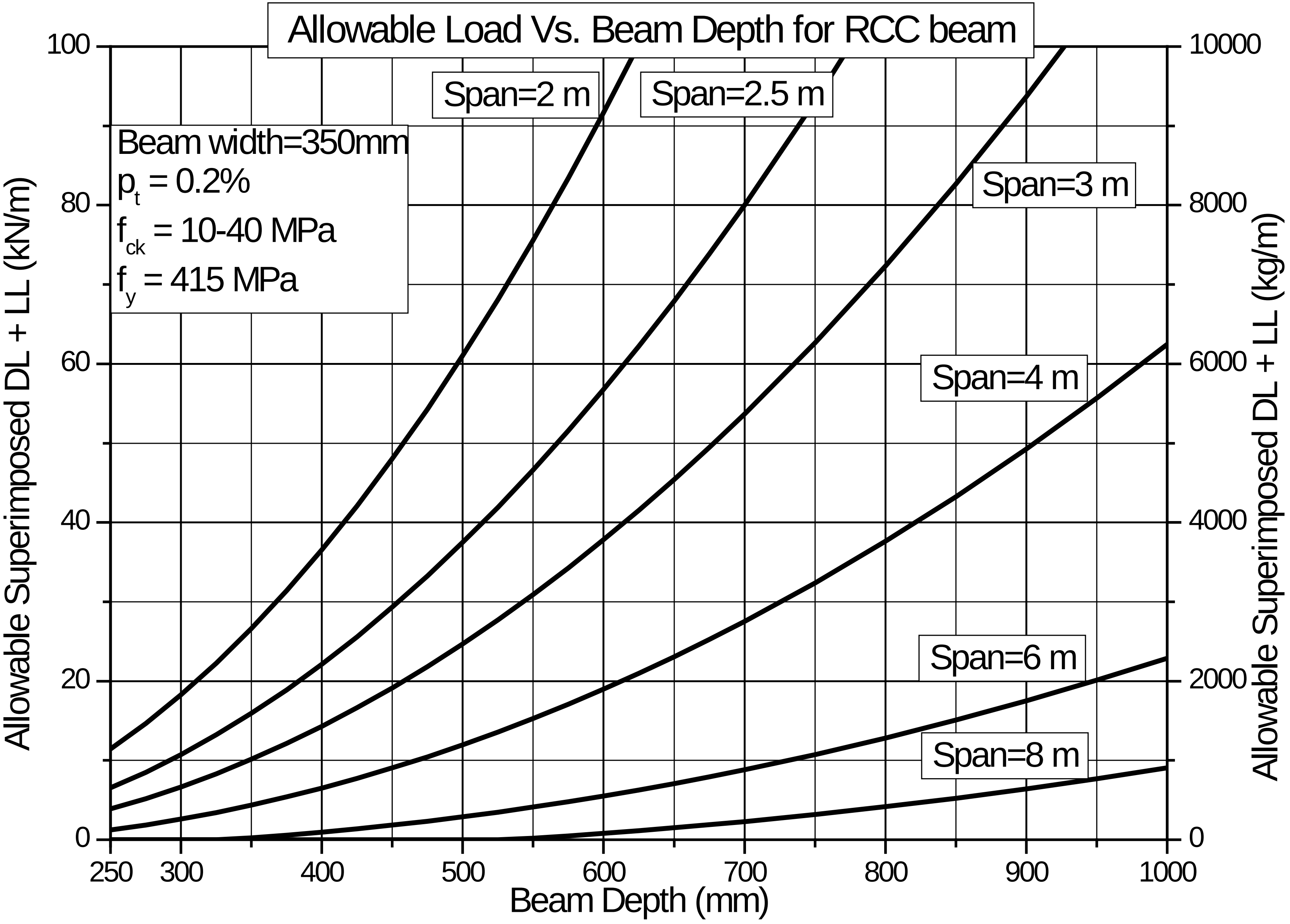


Figure 51: Allowable Load vs. Beam Depth for RCC beam

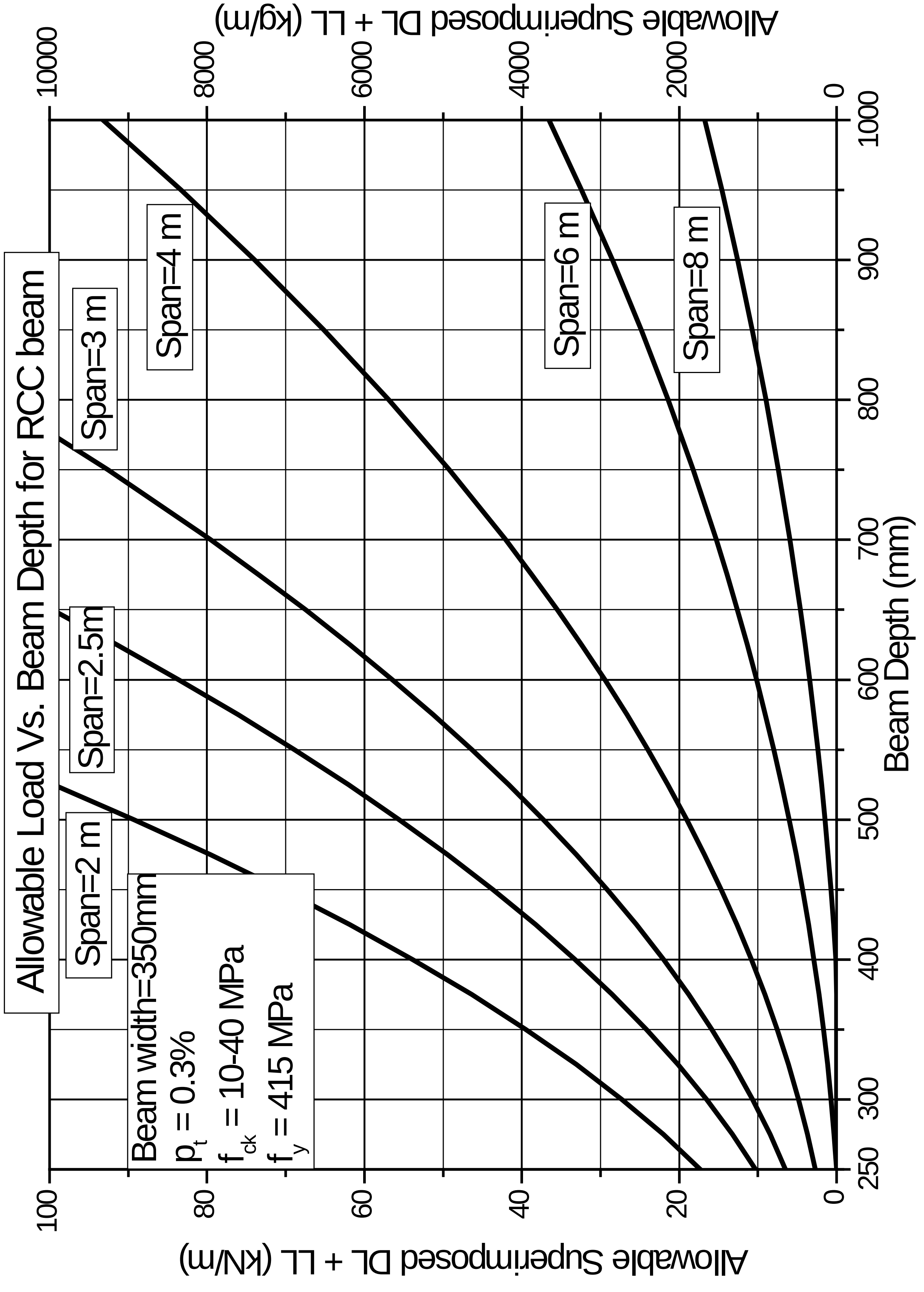


Figure 52: Allowable Load vs. Beam Depth for RCC beam

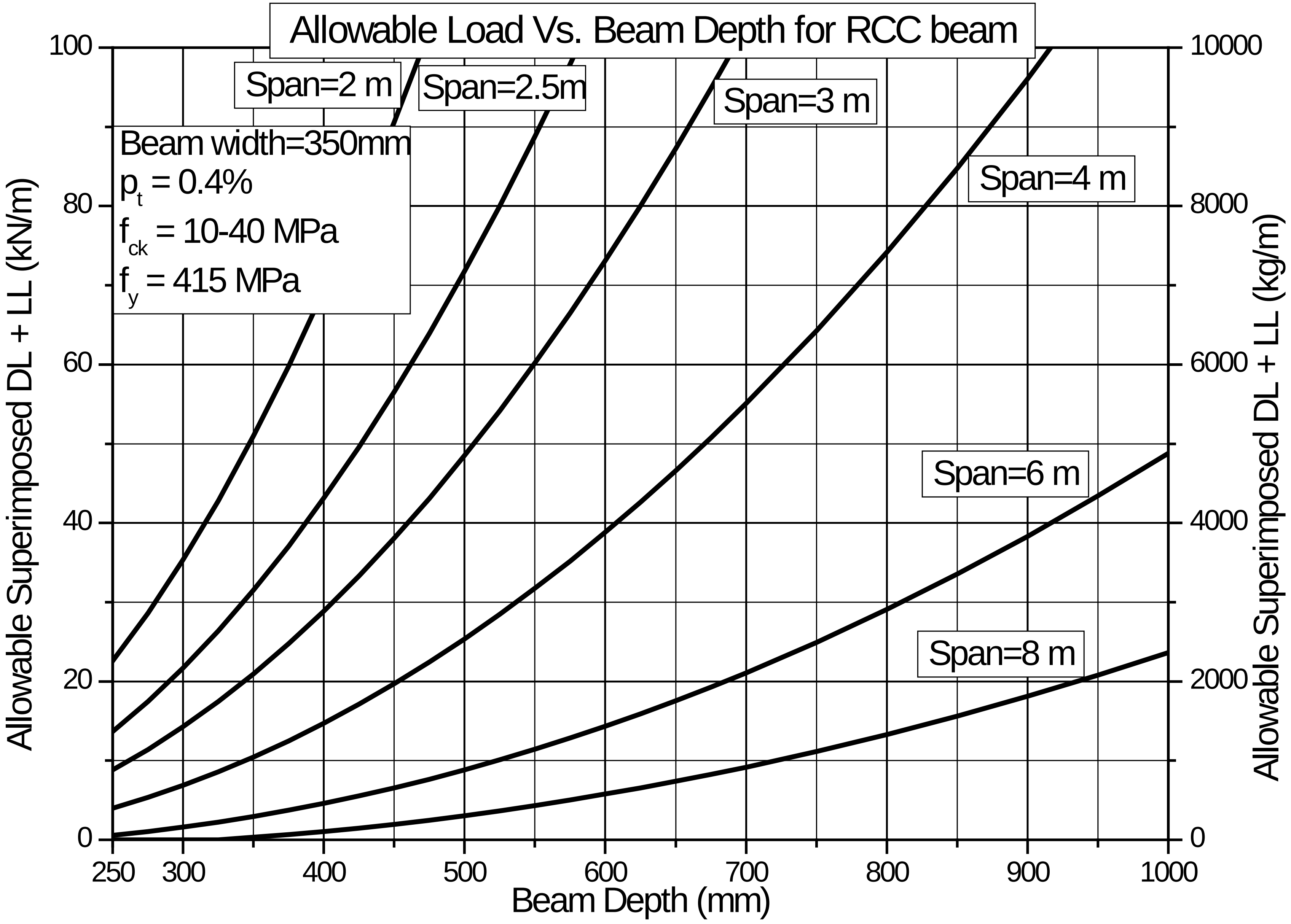


Figure 53: Allowable Load vs. Beam Depth for RCC beam

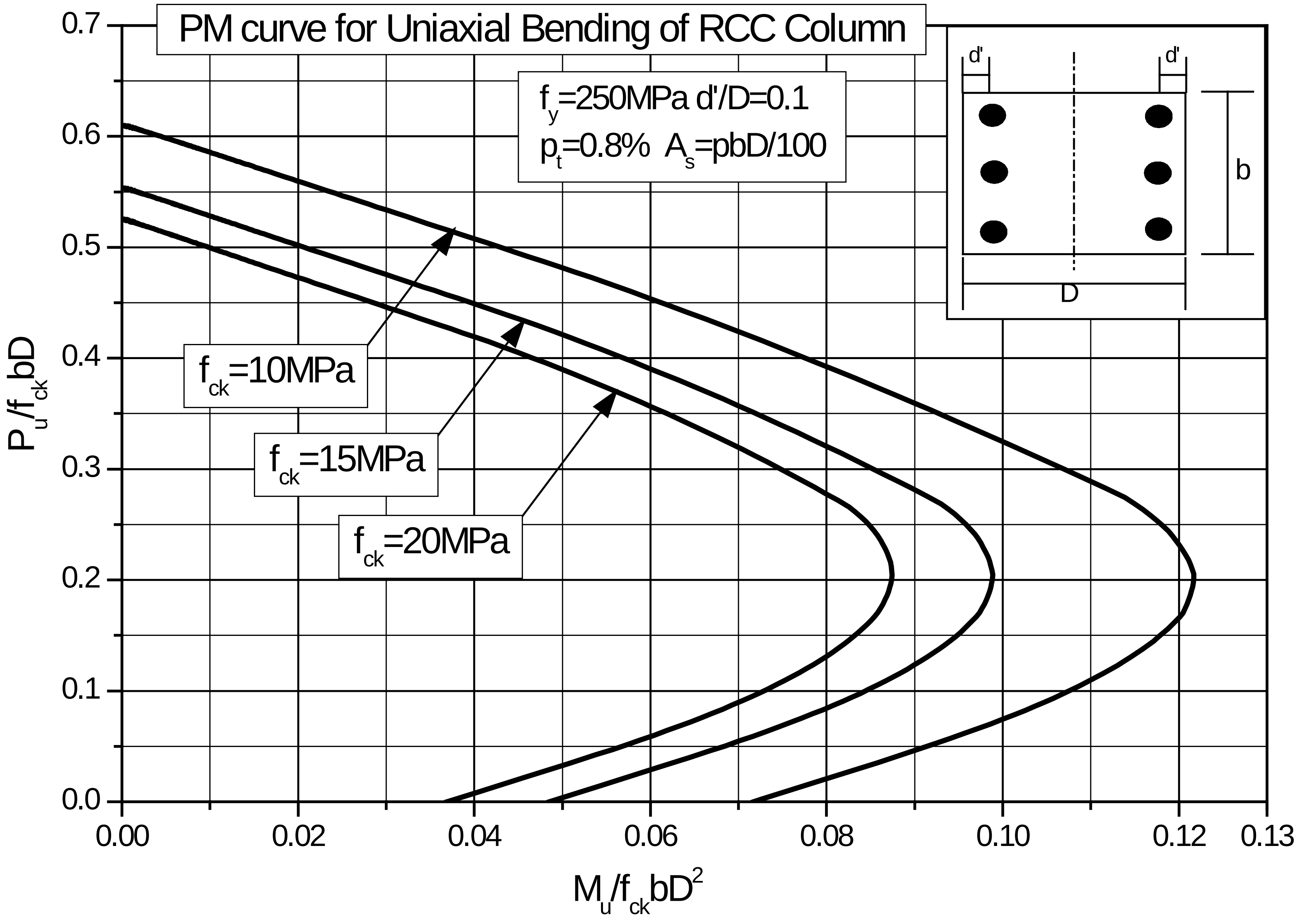


Figure 54: PM curve for Uniaxial Bending of RCC Column

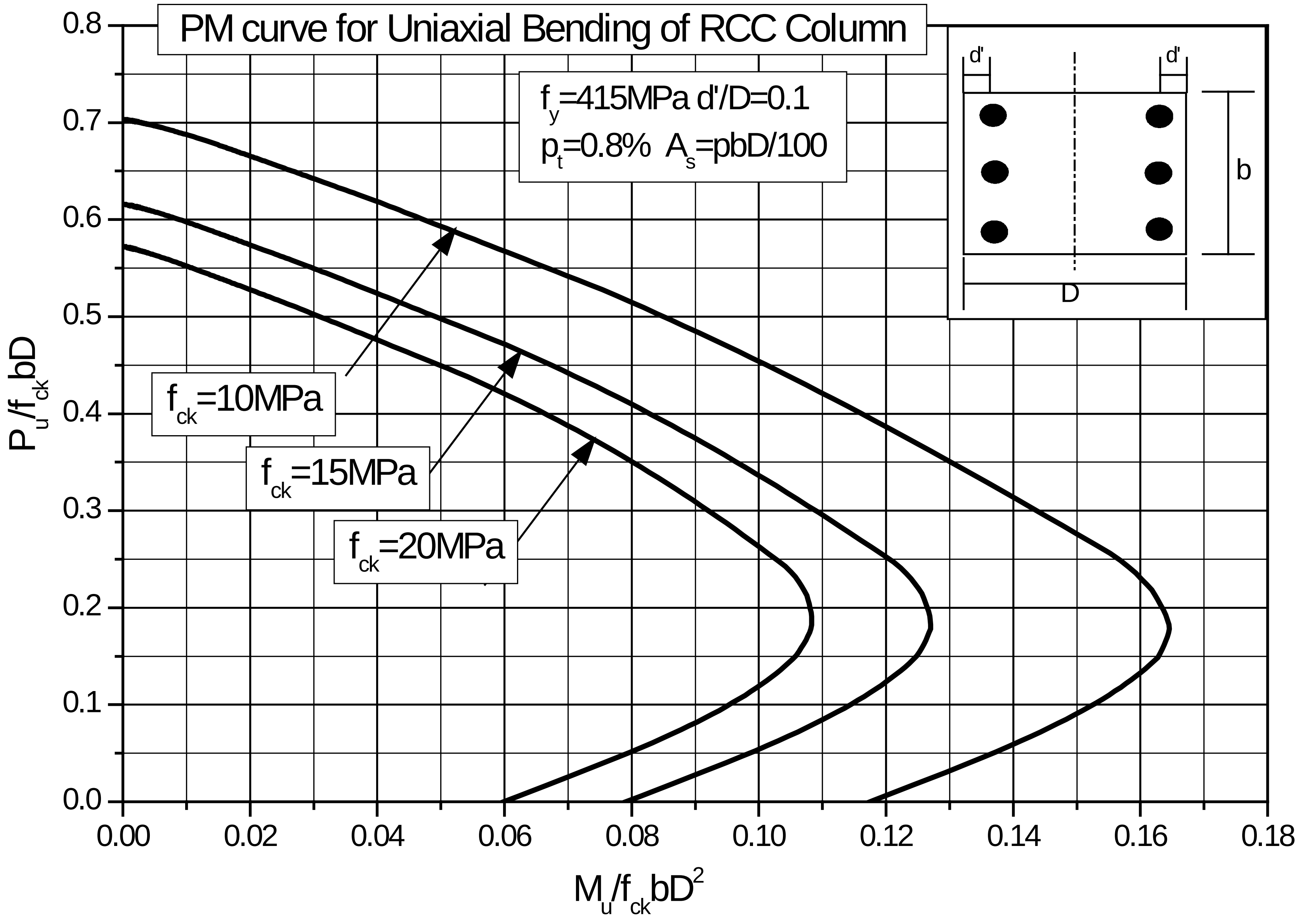


Figure 55: PM curve for Uniaxial Bending of RCC Column

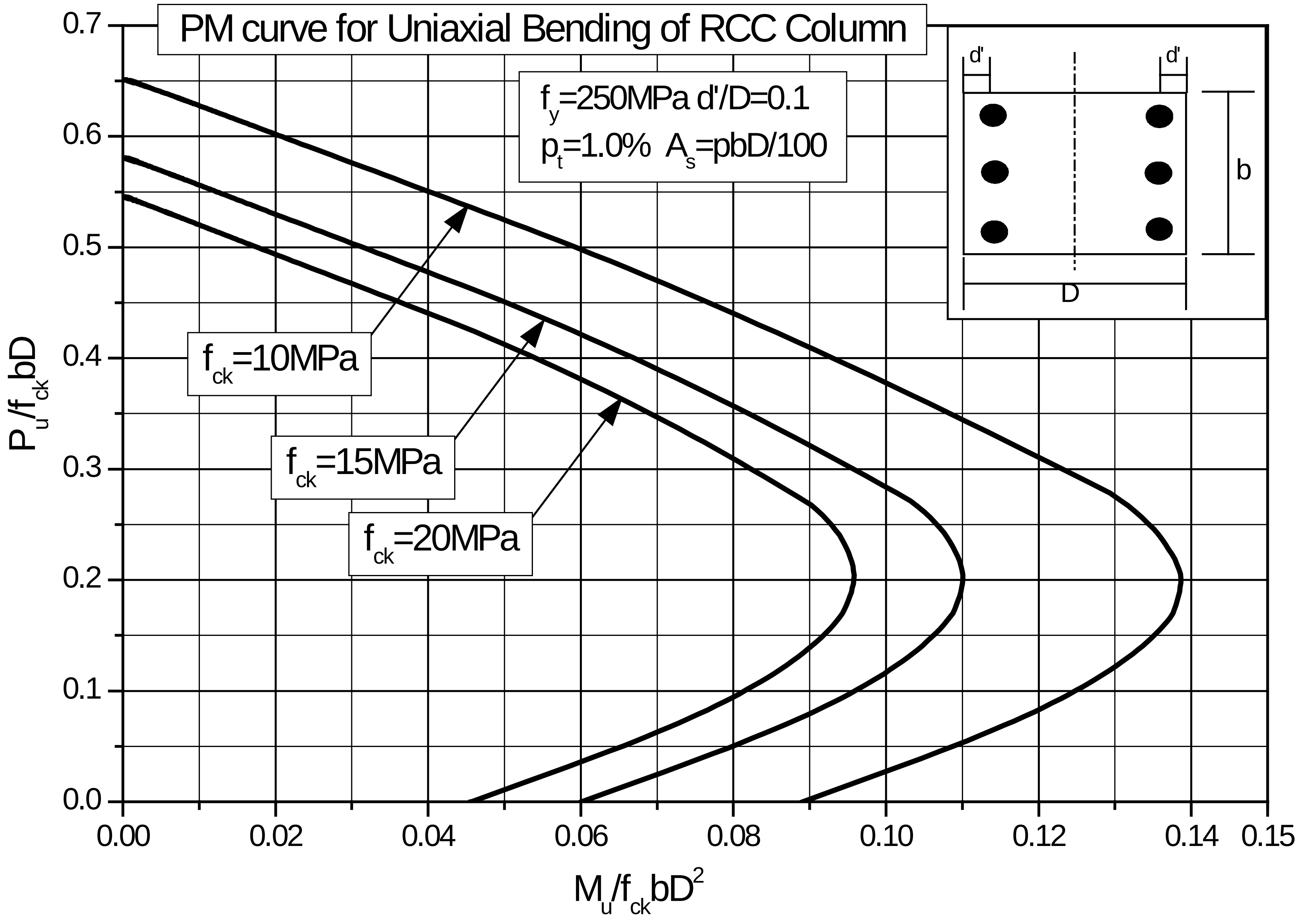


Figure 56: PM curve for Uniaxial Bending of RCC Column

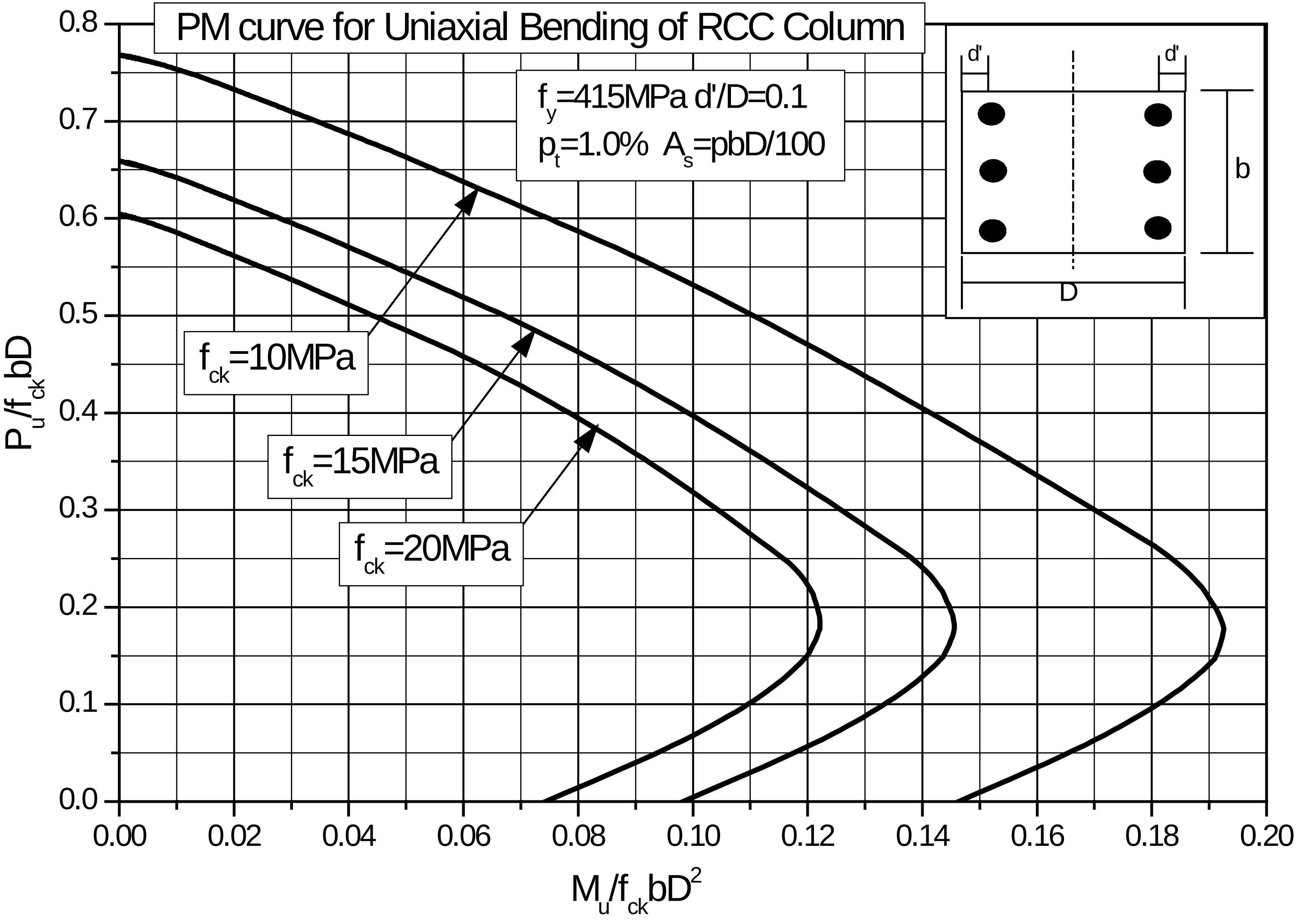


Figure 57: PM curve for Uniaxial Bending of RCC Column

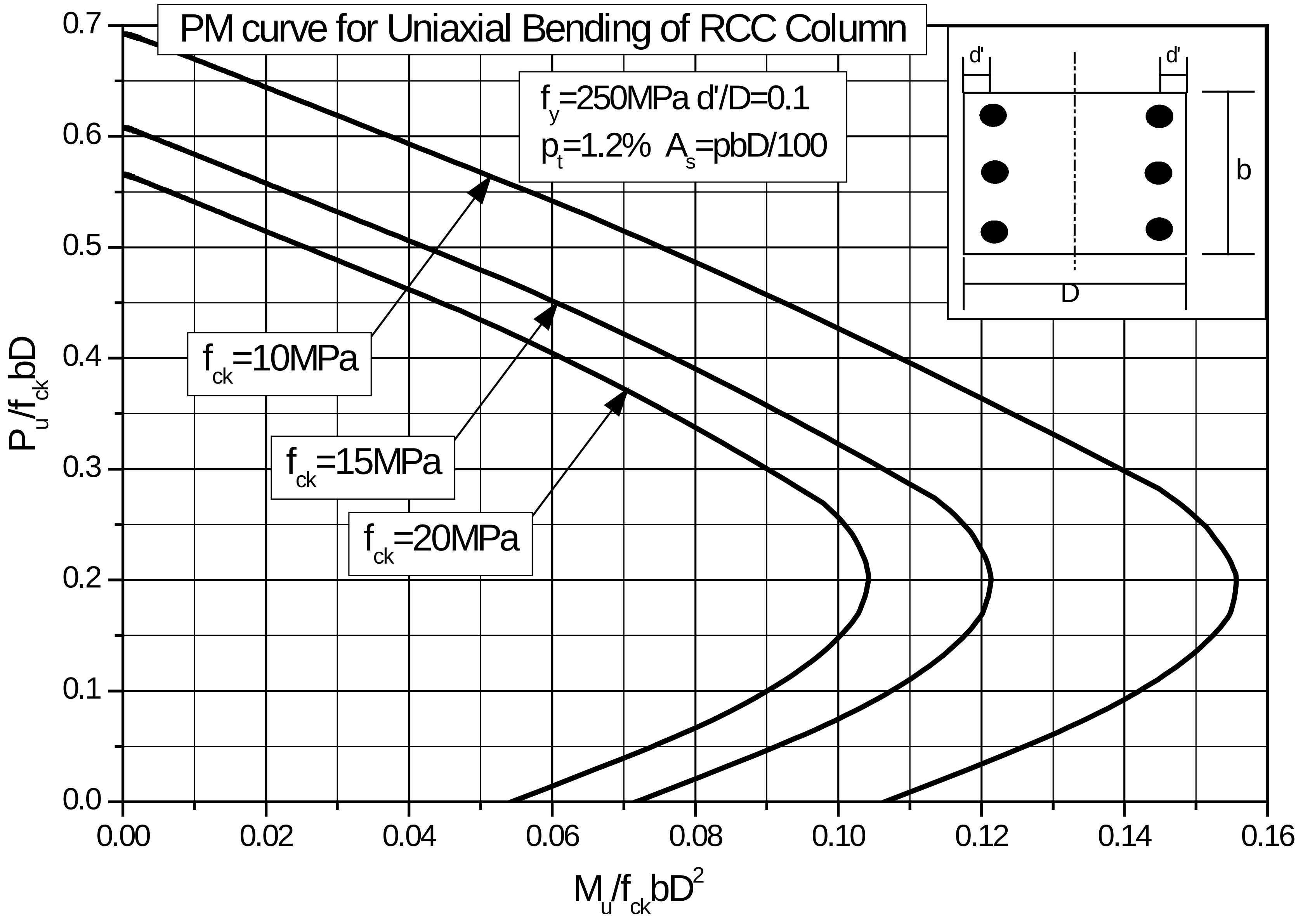


Figure 58: PM curve for Uniaxial Bending of RCC Column

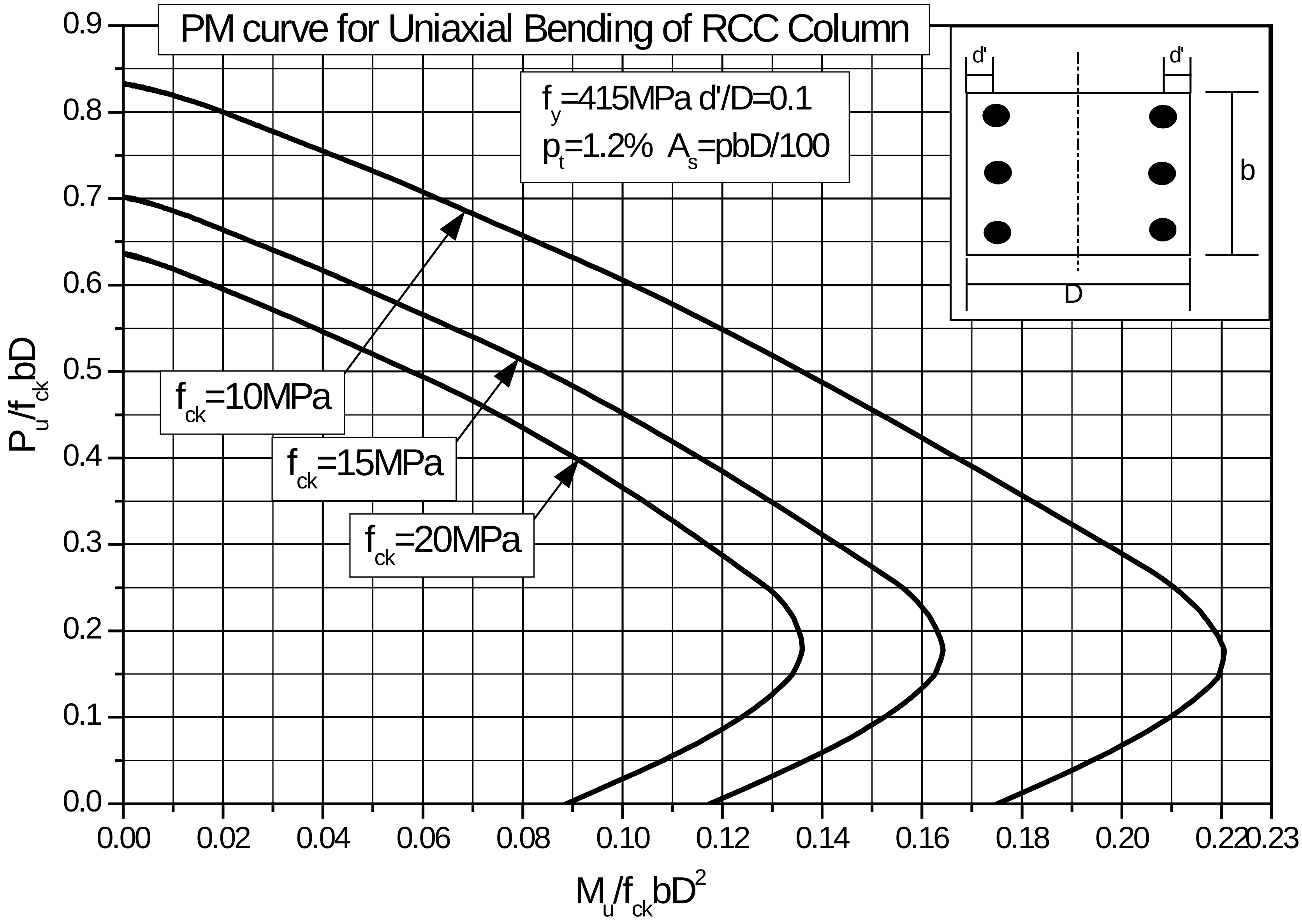


Figure 59: PM curve for Uniaxial Bending of RCC Column

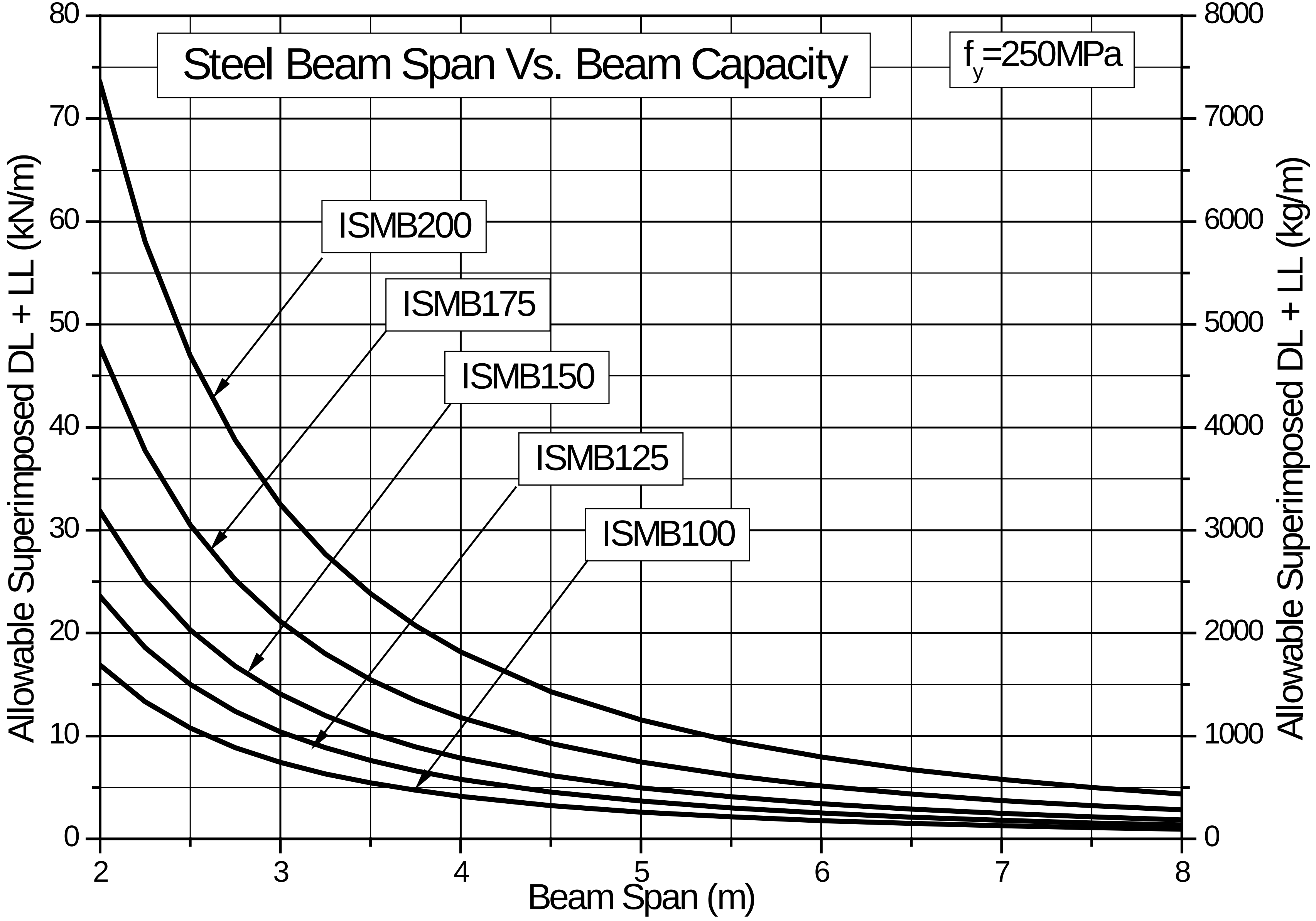


Figure 60: Steel Beam Span vs. Beam Capacity (ISMB 100, 125, 150, 175 and 200)

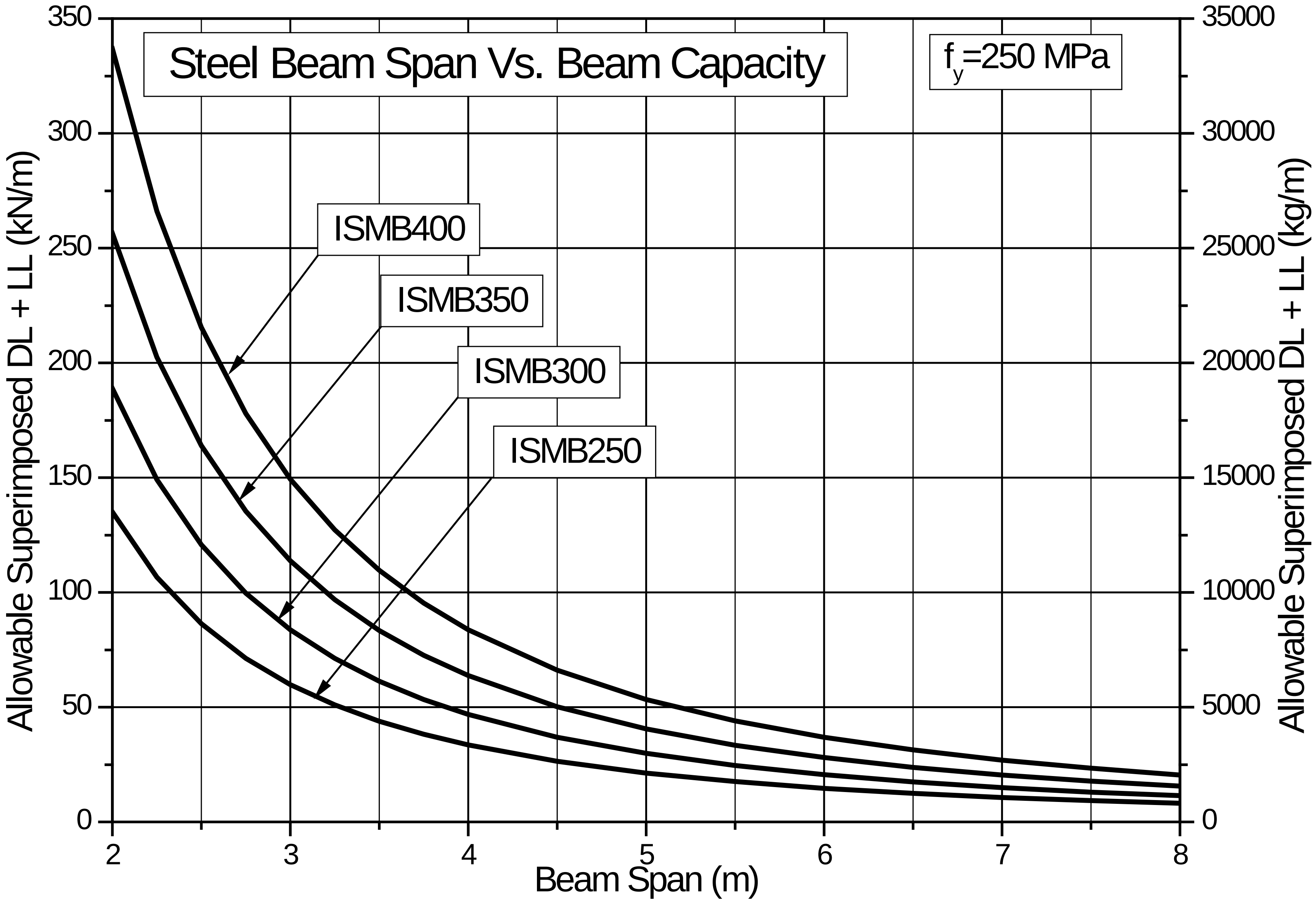


Figure 61: Steel Beam Span vs. Beam Capacity (ISMB 250, 300, 350 and 400)

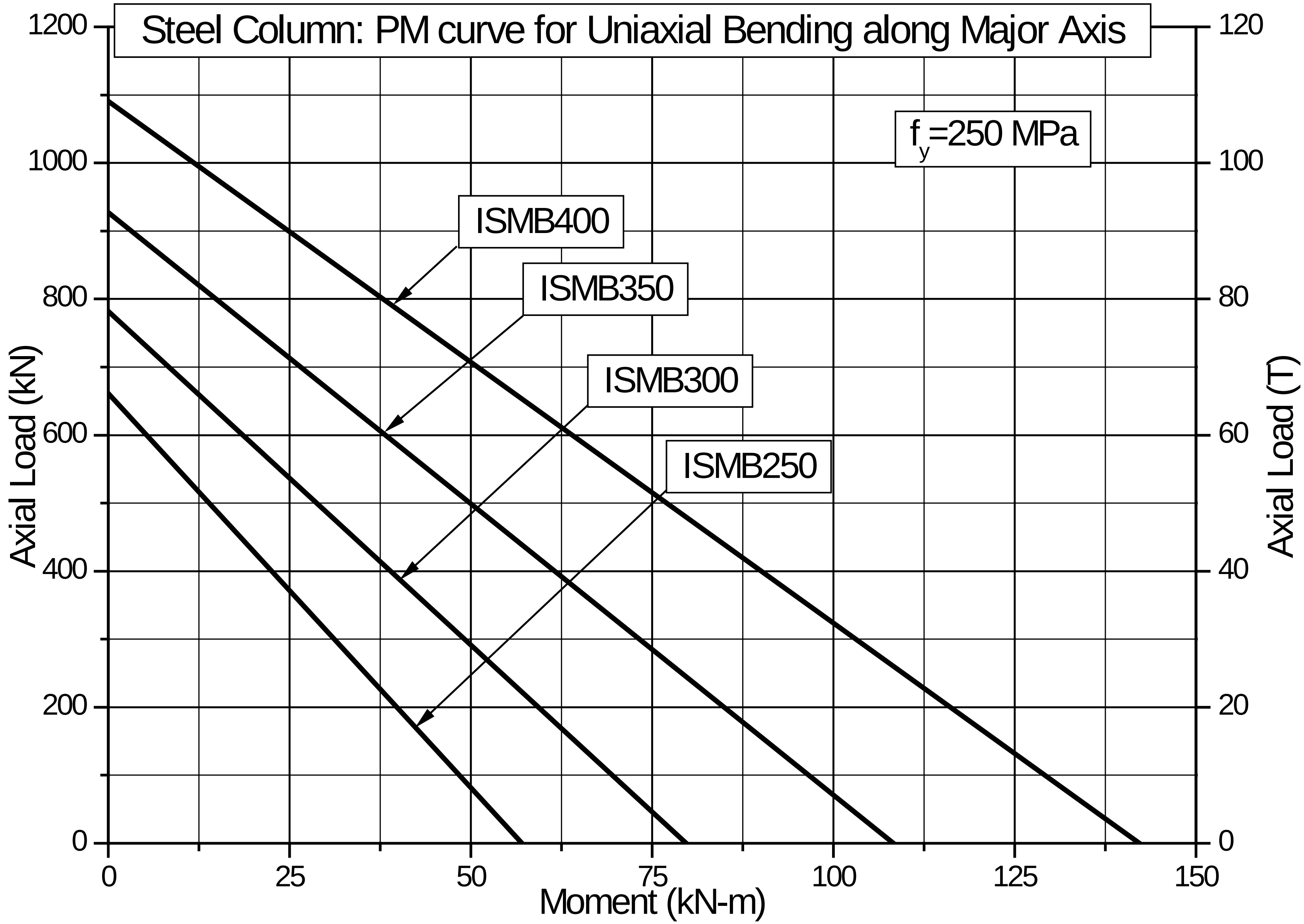


Figure 62: Steel Column: PM Curve for Uniaxial Bending along Major Axis (ISMB 250, 300, 350 and 400)

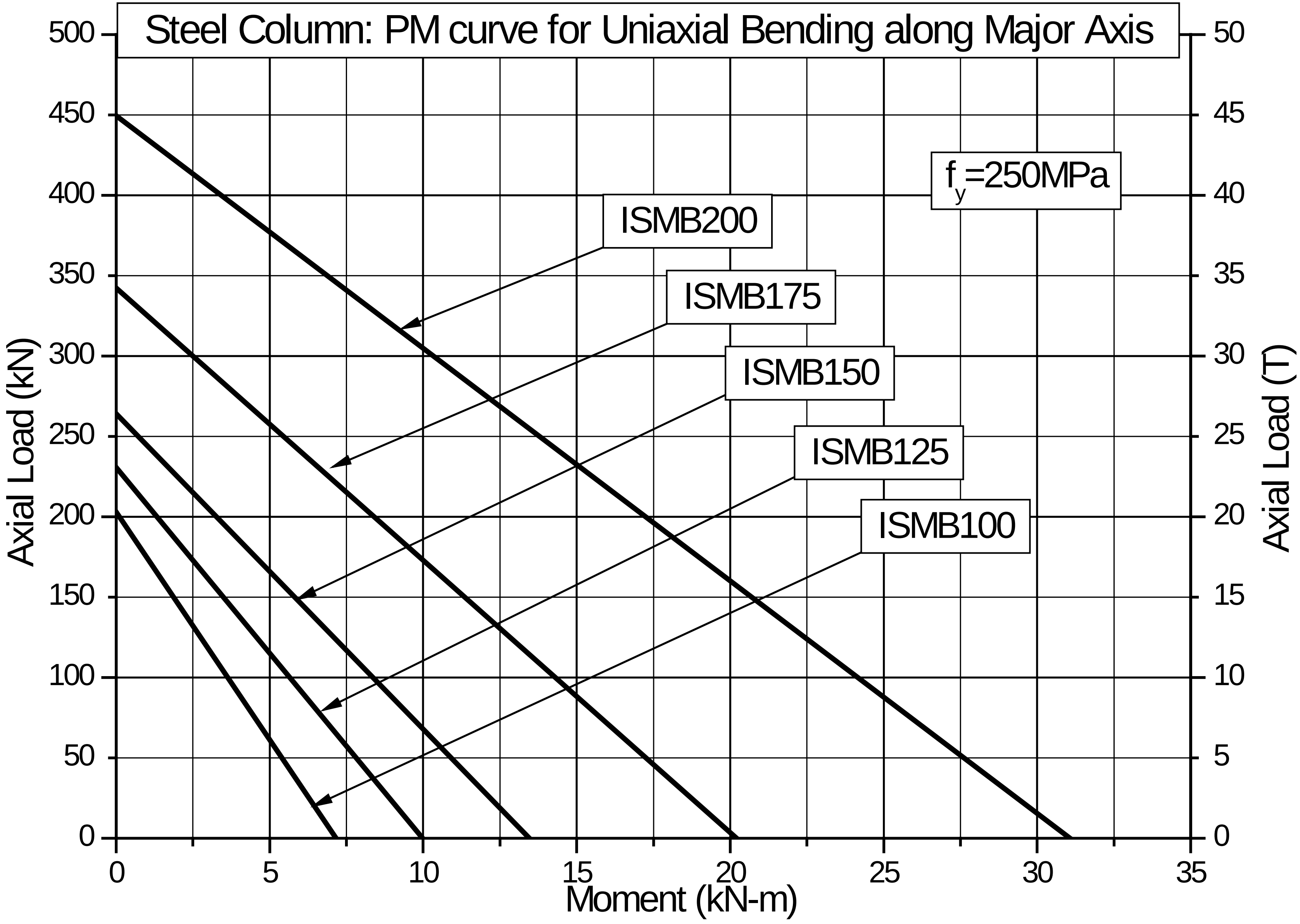


Figure 63: Steel Column: PM Curve for Uniaxial Bending along Major Axis (ISMB 100, 125, 150, 175 and 200)