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TIMBER SELECTION, STRENGTH GROUPING AND STRESS GRADING FOR THE UNIDO PRE-FABRICATED MODULAR WOODEN BRIDGE*

Prepared by

Timber Research and Development Association**

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TIMBER SELECTION

The design selection process for the prefabricated modular wooden bridges is fully explained in the manuals, Annex I shows a chart summarizing the whole process. It can be seen that timber selection is one of the three main essentials and that this is the aspect to which the UNIDO simpified grading rules relate. The following extracts from the manuals enlarge upon this.

Properties of timbers from many developing countries, together with information on strength grouping, stress grading and general timber technology are given in Part 4 of the manuals. The selection of timbers included has been made with care, listing only those which satisfy various criteria. Factors considered were whether the timber was likely to be suitable for bridge construction; whether it would probably be available at a suitable cost, and whether it would be sufficiently durable or capable of being treated. Inevitably however, individual circumstances, and even individual advice, will give rise to cases in which it is required to assess or use a timber not provided for in the manual. Sufficient information is given in Part 4, therefore, to enable the more experienced user to make his own further selection, based on the recommended criteria.

The following steps must be taken by every user of the manuals when dealing with the timber selection stage of the design process:

1. Timber nomenclature

It is necessary to determine the local names, and also the botanical species or combinations of species, of timbers which are on offer. These timbers must be in the form of material which is likely to be available in the sizes and quantities suitable for bridge building. The names given must be linked with the standard timber names, as explained below, and with the information provided in Part 4.

The strength of timber depends considerably upon the species of tree from which the wood is taken. For international scientific purposes, the Latin name of the tree species is also associated with the timber itself. Trees have been treated in the same way as other plants by botanists, and the scientific naming system has evolved over several centuries. For this reason, the Latin description implied in the botanical name may actually refer to some feature of the tree itself, rather than a characteristic of the wood. Nevertheless, despite certain limitations and difficulties in its application, the botanical naming system is the most reliable means of reference, since common, commercial and vernacular names of trees and woods are often imprecise or misleading.

Attempts have been made to standardize trade names, and to relate accepted commercial names of timbers to their scientific names. For example, British Standards 881 and 589:1974 (Reference 1) cover most timbers known to the trade in Britain, which is a prolific importing country, drawing from many sources of supply. ASTM D 1165 (Reference 2) gives a standard nomenclature used in the USA. International standardization is promulgated by FAO, who select a preferred vernacular name and designate it, in capital letters, as a pilot name (Reference 3). Various tropical timber producing countries also publish national standards aimed at conformity of nomenclature (Reference 4).

Further information on nomenclature is included in Part 4. The essential consideration, from the point of view of a person in the field concerned with timber selection for a bridges project, is to obtain a positive identification of timbers offered commercially or recommended locally as suitable. No single piece of simple advice can be given; normally it is desirable to contact national forestry or timber research organizations. TRADA is also able to provide advice, and if help can be requested in a moderate, concise and orderly manner, this may be provided free of charge.

2. Availability

In considering the timbers to be used, practical considerations such as availability, continuity of supply and cost must be paramount. There is a particular tendency in some developing countries, often having a strong tradition of forestry dating back to the colonial era, to issue publications and lists from national institutions which describe a large variety of species which are uncommercialized, infrequently occuring, or which grow only in remote or unlogged regions. Some of these may at first sight appear suitable for bridge building, being described for example as 'very durable'. However, unless good supplies can be made readily available in the required dimensions, then these apparently excellent choices must be rejected in favour of more common timbers.

Chapter 1 of this manual indicates the principal sizes required for the modular panel, the pieces of which are all 50 mm thick, ranging in width from 150 mm to 250 mm. Lengths of up to 3.3 m are required for the modules, and 3.8 m for the normal deck timbers. These size requirements in themselves will preclude the use of many of the finer and more decorative timbers, which tend to be sawn in random dimensions, for non-structural use. In some countries, where a ready market does not already exist calling for wood for local constructional purposes, it may first be necessary to locate sawmills capable of producing the sizes and quality of cutting required, and then to negotiate with them over the species for which suitable logs can be obtained and cut.

3. Assessment

Further assessments should be made, after having determined and verified, the identity of a list of local timbers thought likely to be suitable for bridge building. At this stage, the requirements of availability and continuity of supply should also have been considered. The assessment should then follow the methods given in Part 4. Only a few essential points are mentioned in this section, therefore.

The immediate requirement, from the point of view of the design selection process described in this chapter, is to decide the strength group and hence stress grade, into which the possible timbers fall. The method by which the decision is taken is further described below. At the same time however, a number of other timber technological properties should be examined, following the classifications given in Part 4. This process will further refine the list, eliminating timbers which are less suitable for various reasons. The properties classified in Part 4 are density, strength group, workability, shrinkage, durability and amenability to preservative treatment.

Preservative treatment of timber involves the introduction into the wood structure of stable chemicals which protect it from wood destroying organisms such as fungi or insects. The processes used are well understood, with a long history of successful use. Many wooden bridges, (of older types of design than the [illegible] system) which have been properly protected are still providing service after more than 50 years. The properties relevant to this consideration are durability and amenity to preservation. Durability refers to the natural resistance of the timber to decay and insect attack.

The timbers classified in the highest durability grouping in Part 4 have considerable resistance to fungi, beetles and termites under tropical conditions, even without treatment. However a problem with reliance upon natural durability as an alternative to preservation is that, regardless of how durable the heartwood may be, the sapwood of practically all timbers is perishable. Furthermore, the ease by which sapwood may readily be distinguished from heartwood by rapid visual inspection varies considerably from species to species. Therefore unless assured supplies of sap-free timber in a durable species can be obtained from a reliable source, preference should be given to preservative treatment, ideally by one of the pressure methods described in greater detail in Part 4.

4. Stress grading

Stress grading is an established technique for the selection of structural timber which is intended to ensure that each piece does not contain features that would have an excessively weakening effect. It is impracticable merely to state in specifications that 'all timber shall be free from defects'. Stress grading must be carefully and effectively carried out on the timber chosen for the pre-fabricated modular panels.

During the early stages of a project, this will entail several processes, including some form of training or provision of stress grading skills, and a consideration of the grading aspects of the species shortlisted. Two forms of visual stress grading are described in Part 4. These are for tropical hardwoods and conifers respectively. Both sets of rules provide for two pass grades, or structural qualities of timber. All four grades are equally satisfactory and suitable for use, provided that the grading is performed correctly, and the choice is taken into account in arriving at the final 'stress grade'. 'Stress grade' is a term given a very special and precise meaning, as further explained in Part 4. It indicates a combination of a particular visual grade of structural timber, with a particular strength grouping of the timber concerned. Only when it has been decided which 'stress grade' can be used, is it possible to enter the design tables given below, and choose the number of trusses needed for a given span and loading.

Having studied and practised the simple visual stress grading rules given in Part 4, it will [illegible] trials of the rules on [illegible] samples of the timber[illegible] have been shortlisted in [illegible] grade has been [illegible] strength group of the timber or timbers selected has been determined, then the final stages of the design selection process can proceed. The rules for selection of the 'stress grade' are explained by means of a worked example in the following section.

Selection of 'stress grade':-

Part 4 explains in more detail how timbers used in the pre-fabricated modular wooden bridge system are allocated 'strength groups'. The basis of this grouping is the inherent strength of the type of timber concerned, as determined from tests on small pieces free from defects. Determination of the strength group is only one step therefore in deciding the 'stress grade'. To find the strength group of a timber listed in Part 4, it is merely necessary to look this up, in column (2) of the general classification tables. It will be noted that there are seven strength groups and that these are designated by means of 'S' numbers, with strength group S1 being the strongest, and S7 the weakest.

As an example of the determination of the strength group for a hardwood, the following extract from Table 8 of Part 4 (properties of timbers from Africa) shows that Ekki (Lophira alata) is classed as a strength group S1 timber:

BOTANICAL NAME	PILOT/Common names	(1)	(2)	(3)	(4)	(5)	(6)
Lophira alata	EKKI	H	S1	B	C	A	P/R
	Azobe						
	Kaku						
	Bongossi						
	Eba						

In a similar way, as an example of the determination of the strength group of a conifer, reference to Table 5 of Part 2, giving properties of timbers from Central America, will show that Caribbean pitch pine (Pinus caribaea) is classed as a strength group S4 timber. Relationship between strength group, visual grade and stress grade:-

The following extract of Table 2(a) from Part 4 shows how the strength group is linked with the visual grade in order to arrive at the 'stress grade' of the timber.

Visual grade	Strength group S1	S2	S3	S4	S5	S6	S7
No. 1 Structural	F27	F22	F17	F14	F11	F8	F7
No. 2 Structural	F22	F17	F14	F11	F8	F7	F5

The 'F' number in this table indicates the 'stress grade'. To continue the worked example: supposing it had been determined, from the study of the stress grading rules and trials of their use described earlier, that the visual grade of structural timber known as 'No. 2 Structural' could efficiently be produced in sufficient quantities using Ekki, the S1 group timber referred to previously, then the 'stress grade' indicated would be F22, as shown by the underlined figure in the extract table given above. A similar exercise carried through to this conclusion for the other example, which was the S4 strength group conifer Caribbean pitch pine, supposing the visual grade known as 'No. 3 Structural' had been decided upon, leads to the 'stress grade' F8. This may be verified by reference to Table 2(b) in Part 4.

OBTAINING RESULTS FOR THE DESIGN SELECTION PROCESS

Selection of the number of trusses required for the bridge

Having established the span of the bridge, its load type (H20, HA etc.), and the 'stress grade' (F number) of the timber to be used for the modular panels, it is finally necessary to establish the number of trusses required to make up the girders of the bridge. This is a very simple process using the following tables. One further small but important decision may be required however, dependent upon the stress grade of timber selected.

Use of light- or heavy-chord designs:-

As explained in elsewhere in the manuals, both light-chord and heavy-chord designs are available. The latter were introduced because the design of the original steel parts became more critical than that of the timber, when the possibility of using high 'stress grades' was provided for. The decision to use light or heavy chords affects not only the choice of the steel or timber lower chords themselves, but also the type of plates used in the modular wooden panel.

The use of heavy chords is only considered for 'stress grades' F11 and higher, so the decision is quite simple. If a lesser stress grade than F11 is involved then there is no question of needing heavy-chord panels and steel chords. For F11 itself, it may be economical, or more convenient in a particular project, to use light-chords for bridges of lower loading designations, such as H20 and for spans up to about 18 metres. With the higher loadings (such as HA and HS20) using F11 timber, and with all the higher stress grades from F14 to F27 inclusive, it is normally recommended to use the heavy-chord designs. In some instances, in the following tables giving the number of trusses needed for a given span and loading, the possibility of using either type of chord has been provided for. For complete clarity, the letter symbols 'L' or 'H' are used in the tables for stress grades F11 and higher, to designate the number of trusses required in light-chord and heavy-chord designs.

Truss Tables

Tables such as that shown as Table 1 are used to establish the number of trusses required in a particular bridge design, in accordance with the recommendations given above.

TABLE 1

Number of trusses needed for a given span and loading for Stress Grade F4

Loading	Span (m)							
	6	9	12	15	18	21	24	27
H10	4	4	4	4	6	6	8	-
H15	4	6	6	6	8	-	-	-
H20	4	6	6	6	8	-	-	-
HS15	6	6	8	8	-	-	-	-
HS20	6	6	8	8	-	-	-	-
2/3HA	4	4	6	8	-	-	-	-
HA	6	8	-	-	-	-	-	-

STRENGTH PROPERTIES OF TIMBER

THE STRENGTH OF WOOD

The strength of wood depends considerably upon the species of tree from which the timber is taken. For this reason it is necessary to standardise timber names, and for international scientific purposes the Latin name of the tree species is also associated with the wood itself. The greatest range of strength is found amongst the various tropical timbers. The conifers, commonly used for construction in temperate regions, tend to fall near the middle of the range of tropical timber densities and strength. To illustrate the great range of tropical woods, a timber from Malaysia known as Bitis (botanical species Madhuca utilis) has a bending strength about seven times that of Balsa (Ochroma pyramidale) from Ecuador.

The range of strength of timbers suitable for bridge building is of course somewhat less, since the very low density woods are excluded for many practical reasons. It is nevertheless quite considerable. Just as an example, there are two potentially useful African woods, mentioned because both have good natural durability. One of these, known as Ekki (Lophira alata), has a bending strength about twice that of the other, known as Niangon (Tarrieta utilis).

It is clear from the above that in attempting to specify possible timbers for use in the pre-fabricated bridge system that may be used anywhere in the world, quite a confusing and large list of difficult-to-pronounce Latin names and diverse strength properties would ensue from an attempt to deal with timbers on an individual basis. To avoid this, a grouping system has been adopted throughout the manuals that is largely based on one developed and used for many years in Australia, a country where there was a special need for such a system due to the diversity of indigenous timbers used for construction.

The usual way of establishing the strength of wood is to use standard test methods on small pieces which are carefully cut to avoid any defects which would influence their properties. (There is another, more expensive method applied to a few important timbers used in industrialized countries, but details of this need not be mentioned). These test pieces are known as small clear specimens. By placing timbers into groups according to their small clear properties, it is possible to classify them quite concisely, and to cover thousands of species whose properties have been measured in this way in various timber laboratories throughout the world.

The small clear property strength groups help considerably in providing a brief classification fo. strength, and bring us some way towards having short sets of tables for designs such as those for the modular bridges. Unfortunately, they do not go all the way. This is because the properties measured from the tests on small, perfect specimens are much too high safely to be used in structural design. Stresses used in structural timber codes such as BS 5268 (Reference 5) or AS 1720 (Reference 6) are reduced in several stages from those originally derived from test. Reductions have to be made to allow for facts such as that timber strength is naturally quite variable, even from one perfect piece to another; timber strength varies according to the duration over which the load is applied, and of course like any other structural material, safety factors are necessary. In addition to these reductions, another set of ratios are needed to allow for the influence of features such as grain deviation, knots and other characteristics, that have to be allowed in structural sized pieces of wood as opposed to small clear pieces.

Chapter 3 explains in greater detail how wood is graded for structural purposes. Information is given on simplified grading rules for tropical hardwoods and conifers that have been developed for use in UNIDO projects. Stresses are listed in various structural timber codes for timber graded in a similar manner, following rules that are available in the national standards of the countries concerned. Most industrialized timber-using countries and quite a number of less-developed countries have national stress grading rules. Unfortunately there is some confusion over the names used for the 'safe working stresses'. The British code calls them 'grade stresses', whereas the Australian code refers to them as 'stress grades'. This confusion of nomenclature is unavoidable since both terms are so firmly rooted in all the codes, standards and regulations of the respective countries, that there is little the reader can do but understand and remember the two usages.

The following section gives further details of the strength groups and stress grades that are used for the manuals.

STRENGTH GROUPS AND STRESS GRADES

Strength groups

As outlined above, timbers used in the pre-fabricated modular wooden bridge system have been allocated 'strength groups'. The following definition, given in an Australian Standards Miscellaneous Publication, MP 45 (Reference 7), explains briefly what is meant by this term :

> Where the structural species of timber used in a country are easily identifiable and few in number, it may be appropriate that specific structural design properties be published for each of these species. However, in many countries numerous species are used and it is not practicable to have long lists of design data. Rather it is preferable to group the timber and to provide structural design properties for a limited number of strength groups. In general each strength group will cover a large number of species and commercial mixtures of species. The timbers listed in the following tables are grouped into seven classes according to the Australian system of strength classification.

Full details of the strength grouping method are given in MP 45 but essentially the process consists of ensuring that the small clear properties of the timber concerned are equal to or greater than those for the appropriate group indicated in Table 2, which shows minimum standard strength classifications based on small clear specimens.

TABLE 2

Minimum standard strength classification
based on small clear specimens

Strength group	Moisture condition	PROPERTIES			
		Modulus of rupture (MPa)*	Modulus of elasticity x 10 (MPa)	Maximum crushing strength (MPa)	Maximum shear strength (MPa)
S1	Green	103.0	16.3	52.0	13.1
	12%**	158.0	18.7	81.0	18.7
S2	Green	86.0	14.2	43.0	11.0
	12%**	134.0	16.3	71.0	16.7
S3	Green	73.0	12.4	36.0	9.1
	12%**	114.0	14.2	62.0	15.0
S4	Green	62.0	10.7	31.0	7.7
	12%**	94.0	12.4	53.0	13.1
S5	Green	52.0	9.1	26.0	6.5
	12%**	79.0	10.7	46.0	11.7
S6	Green	43.0	7.9	22.0	5.5
	12%**	67.0	9.1	40.0	10.3
S7	Green	36.0	6.9	18.0	4.6
	12%**	57.0	7.9	34.0	9.1

* 1 Megapascal = 1 N/mm = 145 lbf/in = 10.2 kgf/cm
** Seasoned values estimated from corresponding green values

Stress grades

Design information in the bridge manuals, such as the tables showing the number of trusses required for each loading and span, are based on a determination of the 'stress grade' of the timber concerned. In this context 'stress grade' has the special meaning given in the Australian Standard Timber Engineering Code (Reference 6). The standard's definition of this item is as follows:

> 'The classification of a piece of timber for structural purposes by means of either visual or mechanical grading to indicate primarily the basic working stress in bending for purposes of design and, by implication, the basic working stresses for other properties normally used in engineering design. The stress grade

is designated in a form such as 'F7' which indicates that, for such a grade of material, the basic working stress in bending is approximately 7MPa.'

In Australia, stress grades are derived either through visual methods or by mechanical grading techniques based on measurement of local stiffness. There are set ratios in the relationship between visual grade, strength group and stress grade. All three increment by a factor of 1.25 between each step. As a consequence, there is considerable economy in the actual range of numbers shown in the stress grade tables, since many of the values work out equal and consequently they mesh together. Thus, for a specific grade, timber species from different strength groups may be interchanged. Table 3a and Table 3b show the relationship between visual grade, strength group and stress grade for the simplified grading rules for tropical hardwoods and for conifers which are given in this manual.

It should be noted that a strength group classification system is introduced in the British Standard, BS 5268: Part 2 (Reference 5). The British Standard makes use of 'strength classes' which are defined as 'a classification of timber based on particular values of grade stress'. In a straightforward intepretation of the UNIDO modular wooden bridge system following the methods given in these manuals, structural timber engineering calculations are not necessary. All data for choice of the number of trusses in a bridge are to be found in tables. Under special circumstances where it is required to make calculations however, information may be obtained from TRADA if it is desired to relate Australian strength groupings to design recommendations given in the British code.

Relationship between strength group, visual grade and stress grade

TABLE 3 (a)

Hardwood stress grades

Visual grade	Strength group						
	S2	S2	S3	S4	S5	S6	S7
Structural No.1	F27*	F22	F17	F14	F11	F8	F7
Structural No.2	F22	F17	F14	F11	F8	F7	F5

TABLE 3 (b)

Softwood stress grades

Visual grade	Strength group						
	S1	S2	S3	S4	S5	S6	S7
Structural No.3	F17*	F14	F11	F8	F7	F5	F4
Structural No.4	F14	F11	F8	F7	F5	F4	F3

* The 'F' numbers in the body of the table indicate the Australian 'stress grade'

KEY TO WORLD REGIONS FOR CLASSIFICATION

The following section presents the general classification of the properties of tropical hardwoods and tropical softwoods (conifers), in tabular form, divided into geographical regions and appropriately referenced.

The map below depicts the zones in which these timbers may be found:

TABLE 4

PROPERTIES OF TIMBERS FROM
CENTRAL AMERICA

HARDWOODS

BOTANICAL NAME	PILOT/Common names	(1)	(2)	(3)	(4)	(5)	(6)
Achras zapota	SAPODILLA	H	S3	C	C	A	M/R
	Zapota						
	Nispero						
Andira inermis	ANGELIN	U	S3	B	A	B	P/M
	Almendro						
	Batseed Coraro						
	Amargoza						
Bucida buceras	UCAR	U	S1	C	C	B	R/R
	Bullywood						
	Pucte						
Calophyllum brasiliense	SANTA MARIA	M	S4	B	B	B	P/R
	Palo Maria						
	Krassa						
	Galba						
Dicorynia guianensis	BASRALOCUS	U	S3	A	B	A	R/R
	Angelica						
	Angelique						
Dipholis salicifolia	BUSTIC	U	S3	B	B	B	-/R
	Jubilla						
	Chachiga						
	Nispero amarillo						
Dipteryx odorata	TONKA	H	S1	B	C	A	M/R
	Kumaru						
	Koemaroe						

KEY TO COLUMNS:-

(1) Density
(2) Strength group
(3) Workability
(4) Shrinkage
(5) Durability
(6) Amenability to preservative treatment, sap/heart

For all tables in this section see map on page 13 for key to regions

TABLE 4 (Continued)

PROPERTIES OF TIMBERS FROM
CENTRAL AMERICA

HARDWOODS

BOTANICAL NAME	PILOT/Common names	(1)	(2)	(3)	(4)	(5)	(6)
Hymenaea courbaril	COURBARIL	H	S3	B	B	A	P/R
	Teina						
	Guapinol						
	Cuapinol						
	Copal						
Licania ternatensis	BOIS GRIS	H	S2	C	B	B	-/R
	Bois diable						
	Bois de masse						
Manilkara bidentata	BALATA	U	S1	B	B	A	R/R
	Bulletwood						
	Ausubo						
	Purgo						
Symphonia globulifera	MANNI	M	S3	A	A	B	R/R
	Barillo						
	Cerillo						
	Leche Maria						
Tabebuia guayacan	GUAYACAN	H	S1	C	C	A	R/R
	Lapacho						
Terminalia amazonia	Nargusta	U	S3	A	B	A	M/R
	Fakadi						
	Guayabo						
	White Oliver						

KEY TO COLUMNS:-

(1) Density
(2) Strength group
(3) Workability
(4) Shrinkage
(5) Durability
(6) Amenability to preservative treatment, sap/heart

TABLE 5

PROPERTIES OF TIMBERS FROM CENTRAL AMERICA

CONIFERS

BOTANICAL NAME	PILOT/Common names	(1)	(2)	(3)	(4)	(5)	(6)
Pinus caribaea	Caribbean pitch pine	M	S4	A	B	B	P/M
	Constanero						
	Aste						
	Pinoauau						
	Pino macho						
Pinus oocarpa	Ocote pine	M	S4	A	B	B	P/R
	Pino ocote						
	Pino blanco						
	Ocote						

KEY TO COLUMNS:-

(1) Density
(2) Strength group
(3) Workability
(4) Shrinkage
(5) Durability
(6) Amenability to preservative treatment, sap/heart

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   Part 1. Limit state design, materials and workmanship (for later publication).

   Part 2. Code of practice for permissible stress design, materials and workmanship. 1984.

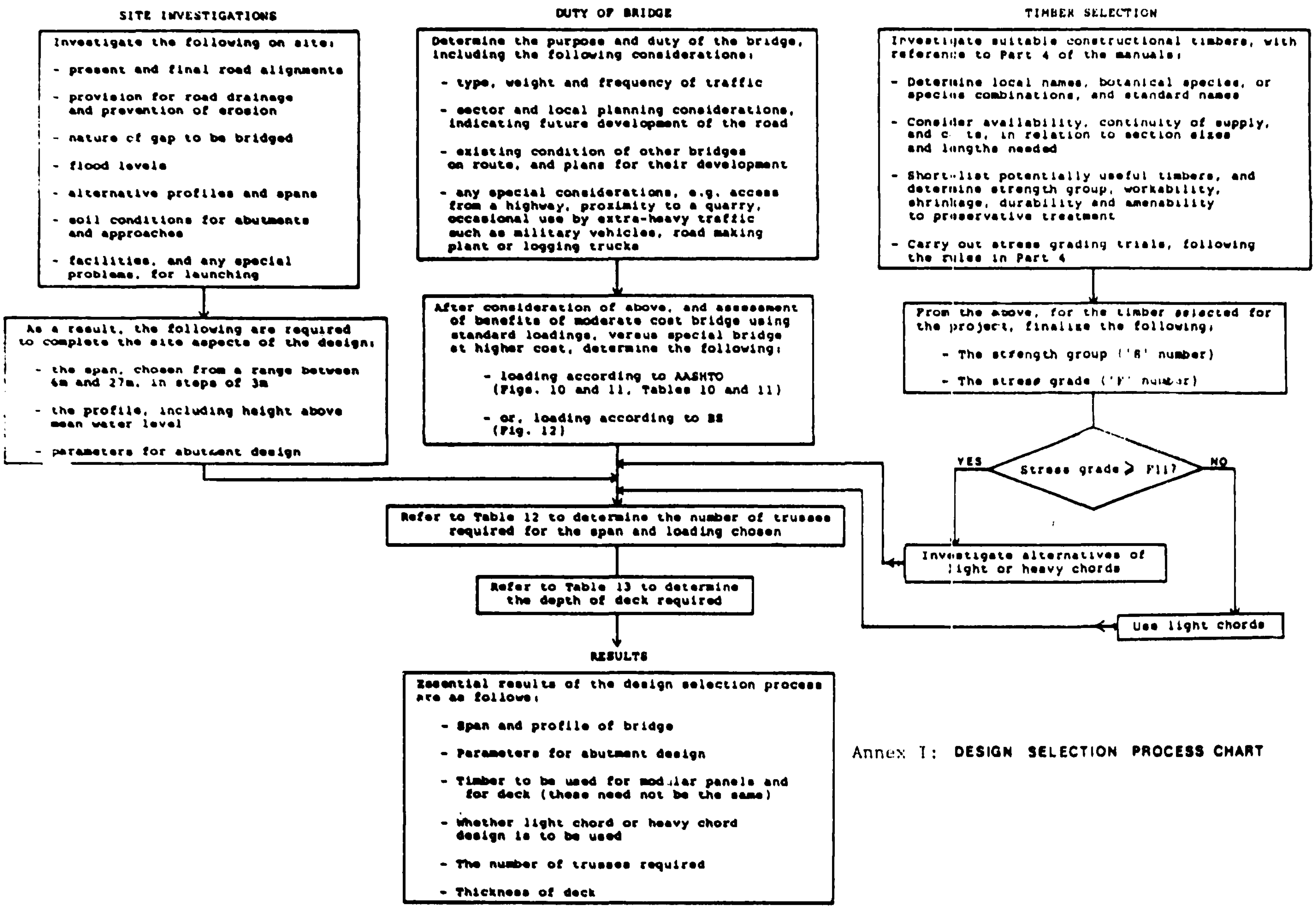
   Part 3. Code of practice for trussed rafter roofs, (in course of preparation).

   Part 4. Fire resistance of timber structures.
   Section 4.1 Method of calculating fire resistance of timber stud walls and joisted floor constructions. (In course of preparation).

   Part 5. Preservative treatment for constructional timber. (Revision in course of preparation).

   Part 6. Code of practice for timber frame wall design, (for later publication).

   Part 7. Recommendations for the calculation basis for span tables (in course of preparation).



Annex I: DESIGN SELECTION PROCESS CHART