BUILDING STRUCTURES

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Introduction

This book is intended primarily for students of architecture, building and engineering or anyone else who needs to understand how building structures behave under load. This book explains the concepts that are required to achieve this understanding. This is done by developing a **conceptual approach** which enables the structural behaviour of any building to be understood. In developing this approach the complex process of **structural design** becomes clear.

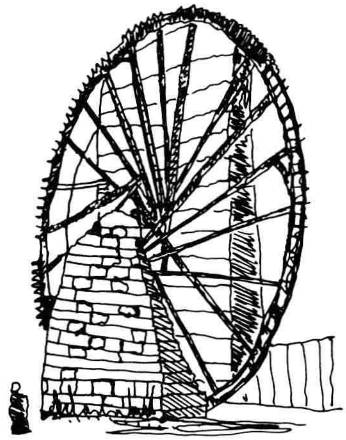
The conceptual approach is presented by description and diagrams without the use of any mathematical ideas. The concepts are introduced by applying them to very simple structures then the understanding is deepened by the gradual introduction of more complex structures. In the penultimate chapter the structural behaviour of a number of existing buildings is explained by applying the conceptual approach.

Although few people give structures or structural design any thought they are surrounded by natural and designed structures. They live in them, travel in them, eat with them, sleep on them, they contribute to almost every aspect of their lives. In pre-historical times humans routinely used structures. Indeed, humans, animals and plants are themselves structures. Many animals build structures, for example birds' nests and spiders' webs. Most groups of pre-historical people regularly used structures in their daily lives. They built forms of housing and constructed boats, bridges, weapons and utensils. Each group tended to produce different designs for their artefacts, how this design process worked is not known, but eventually, **traditional** designs evolved. These traditional designs became fixed and part of the total culture of the group.

When groups of people became **civilisations**, that is an evolving rather than a static culture, new types of buildings were required, temples, storehouse, castles and so on. As the traditional methods no longer applied new technology and design processes were required. These did not always lead to success.

The central requirement for all design processes is to have a method of evaluating the outcome of the proposed design. In the traditional system there are no new problems and the performance of all artefacts is know from experience.

It is clear that early civilised builders thought deeply about their new buildings and often appeared to have clear ideas how their structures behaved. However the acquisition of the technical understanding of structural behaviour was slow and took a long time. It was only during the 19th century that the majority of this knowledge was discovered. This, of course, did not prevent builders constructing the most amazing structures, from pyramids to cathedrals and from catapults to water wheels.



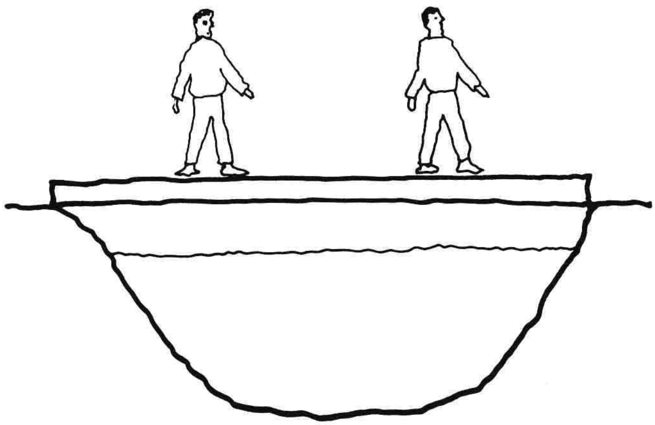
The successful design of any structure requires a satisfactory answer to the following questions:

- **Is the structure strong enough?**
- **Is the structure stiff enough?**

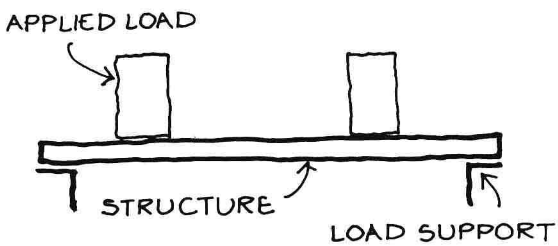
Although this may be stating the obvious the answers may not be readily obtainable. Furthermore, before attempting to answer these questions, two further questions must be answered. These are:

- **What is the structure?**
- **What are the loads?**

The most common answer to the question **what is an (engineering) structure?** would be along the lines **something that carries loads**. Whilst there is truth in this it needs to be extended to the concept of carrying loads from one place to another, that is **transferring loads**. A simple example illustrates this. If people want to cross a stream then a plank could be used as a bridge. Whilst people are on the bridge their weight **(the loads)** are transferred from a point over the water, which cannot directly support them, to points on the banks which can.



The purpose of the plank is to **transfer** the point of load application to the point of load support. The plank does this by acting as a **structure**. The diagram can be re-drawn showing the **applied loads** (the people), the **structure** (the plank) and the points of **load support** (the banks of the stream). It is more usual call the load supports the **reactions**.



This load transferring function is the main purpose of all structures, whether it is a chair or the Forth railway bridge.

The role of structural design is to choose structures which will transfer the loads satisfactorily. However this is far easier said than done because there is a wide choice of structural forms and a range of structural materials which can be used. Furthermore demonstrating that the chosen structure will perform satisfactorily can often be a major task.

CHAPTER 1 *Loads and load paths*

A structure's main function is to **transfer loads**, but before considering the form of a structure a clear idea of what loads it has to transfer is required. In other words an answer to the question **'what are the loads ?'**.

The sources of loads can be divided into **natural**, **useful** and **accidental** loads. Natural loads occur due to the existence of the structure in the world; useful loads are ones that occur from the purpose of the structure; and accidental loads occur from the misuse of the structure.

1.1 Natural loads

All structures on the surface of the Earth have to resist the force of **gravity**. This force acts through a body in a line joining the body with the centre of the earth (Fig.1.1).

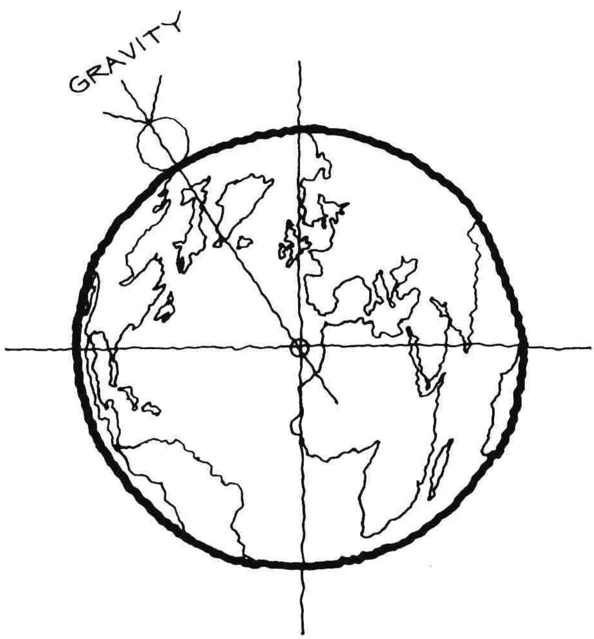


Fig.1.1

However at the local level these forces can be considered vertical (Fig.1.2).

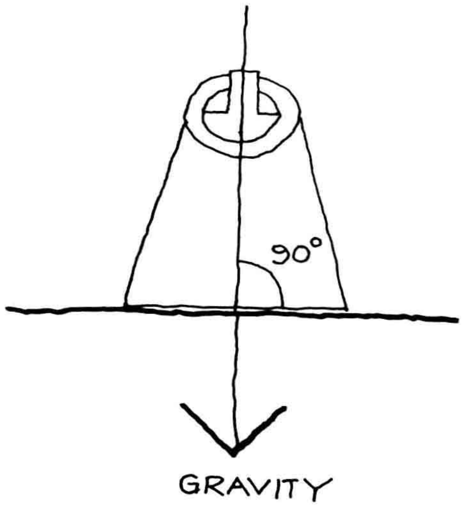


Fig.1.2

So the first source of **natural** loads is the **gravity load**. Returning to the first example, the plank across the stream, this means that the plank has to transfer its own weight, usually called **self-weight**, to the support points (Fig.1.3).

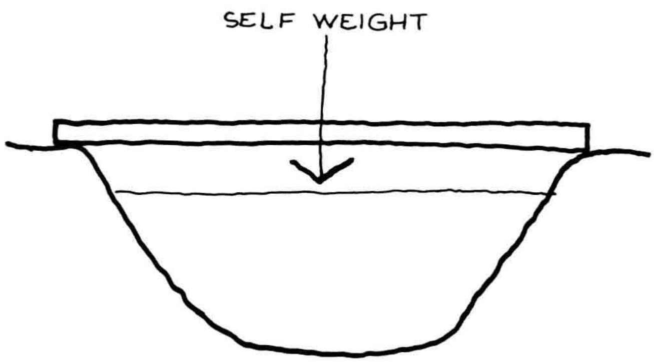


Fig.1.3

Due to regular and continuous changes in atmospheric pressure from place to place on the Earth's surface air flows across the surface of the Earth, that is wind. All structures built on the Earth's surface have to resist the forces from wind. Near to ground level the wind can be considered to blow along the surface. This not true for the whole of the atmosphere, as any pilot knows.

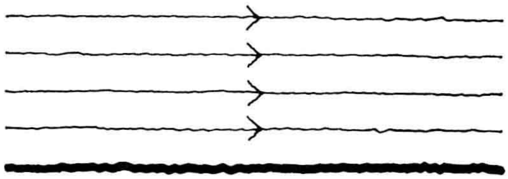


Fig.1.4

If an obstruction is placed in the path of the wind it alters the pattern of the wind flow. Which is why kites and 'planes fly and boats sail. If the object is fixed to the Earth's surface, like a building, the wind must flow around and over it.

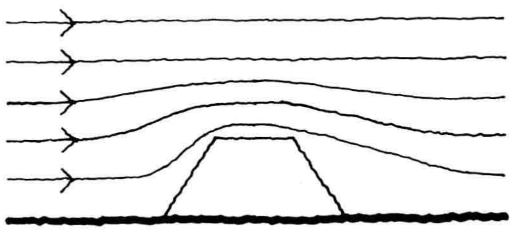


Fig.1.5

How the wind flows around and over an object depends both on the wind speed and the shape of the object. These are the basic questions considered by the complex subject known as **aerodynamics**. But the alteration in wind flow pattern will always cause a **force** on the interrupting object. It is important to notice equating the alteration of the wind flow pattern to a force or **wind load** is an intellectual feat which is intended to clarify the effect of the wind.

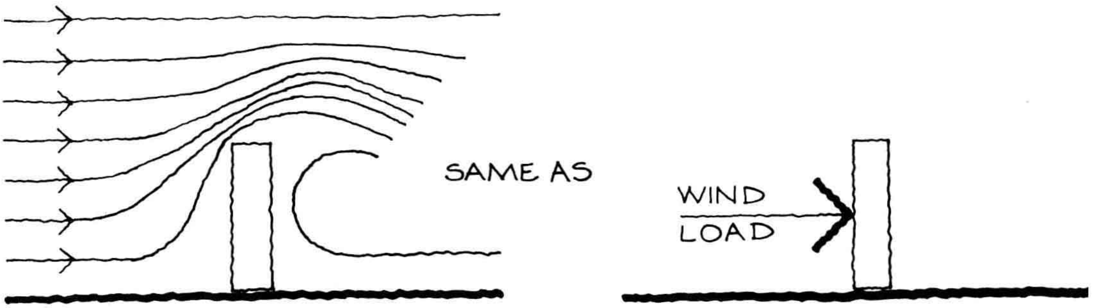


Fig.1.6

This can readily be felt by holding a flat object in the flow of a stream. This is why canoes and people can propel themselves through water.

Although the pattern of wind flow around buildings is complex (very!) the resulting loads from the alteration of wind flow are predominately at right angles to the surfaces of the building.

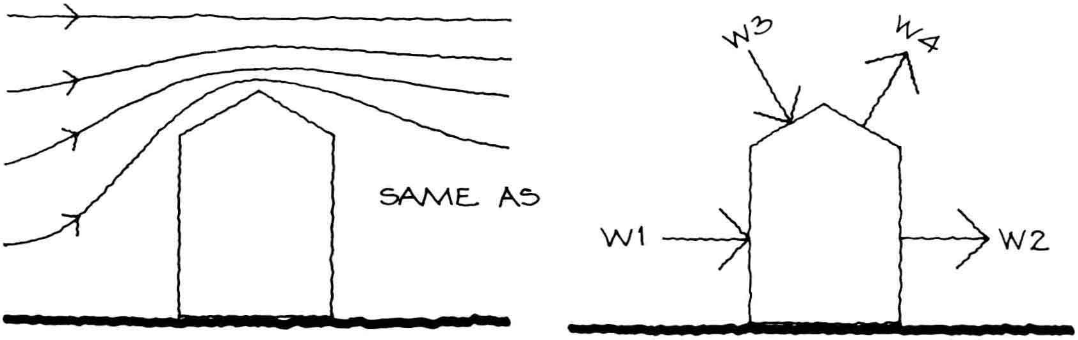


Fig.1.7

So, for the pitched roofed building shown in Fig.1.7, the alteration in wind flow will cause four loads. The loads W1 and W2 are on, and at right angles to the walls, and the loads W3 and W4 are on, and right angles to the roof slopes. These are **wind loads.**

As far as buildings and their supporting structures are concerned **gravity** and **wind** loads are two types of **natural** loads they always have to resist.

There are other natural loads that the structure may have to resist. These are **earth** or **water pressure, earthquakes, temperature**, and **ground movement.**

If the local shape of the Earth's surface is altered to site the building, as it often is, then parts of the building and its structure may be subject to loads from **earth pressure.** This because the natural surface has found a shape that is at rest (not over geological time of course). So, rather like the wind flow, an alteration will cause forces. If dry sand is piled into a heap, there is a maximum slope for the sides.

Fig.1.8

What is happening inside the heap is complex, and is further complicated by the addition of water, (which is why sand castles can be made). If, however, a heap with a vertical side is required, forces are needed to keep the heap in the **unnatural** shape.

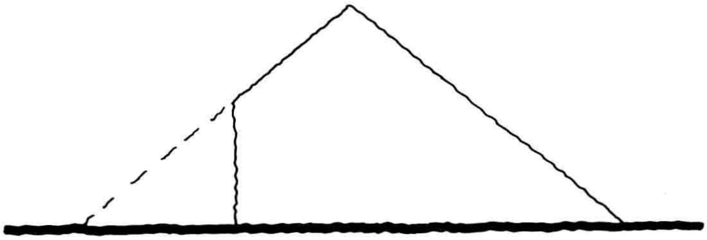


Fig.1.9

This is usually done by building a (retaining) wall. Because the heap wants to return to a natural shape, shown by the dotted line in Fig.1.10, the wall must hold back all the sand above the dotted line.

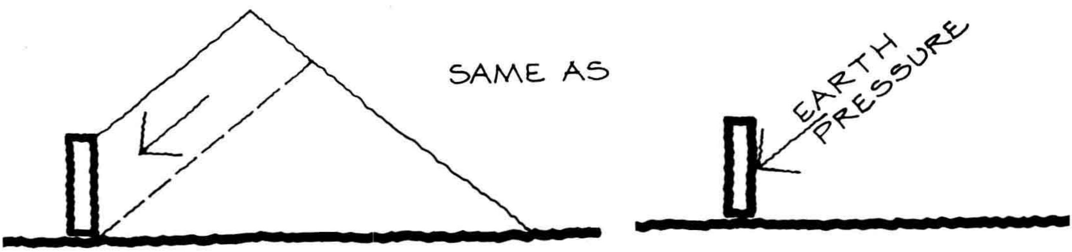


Fig.1.10

This causes loads on the wall. In buildings, this occurs when the building has a basement, or is built into a sloping site.

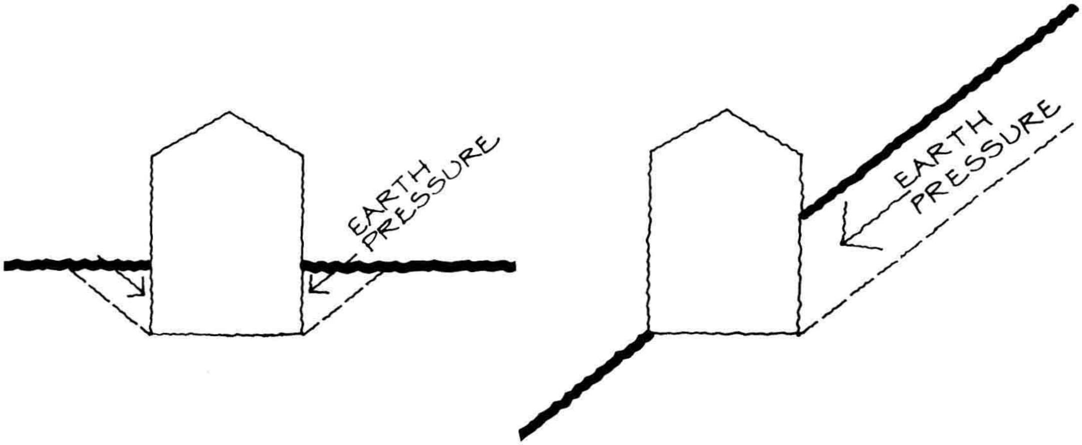


Fig.1.11

In these cases the structure has to resist **natural** loads from **earth pressure**.

Under the surface of the Earth, depending on the local geology and climate, there will be, at some level, water. The top level of this water is called the **water table**. This level may be at the surface, swamps, bogs and beaches, or many metres down in deserts. If the siting of the building interrupts the natural water table an **unnatural water table** is created around and under the building.

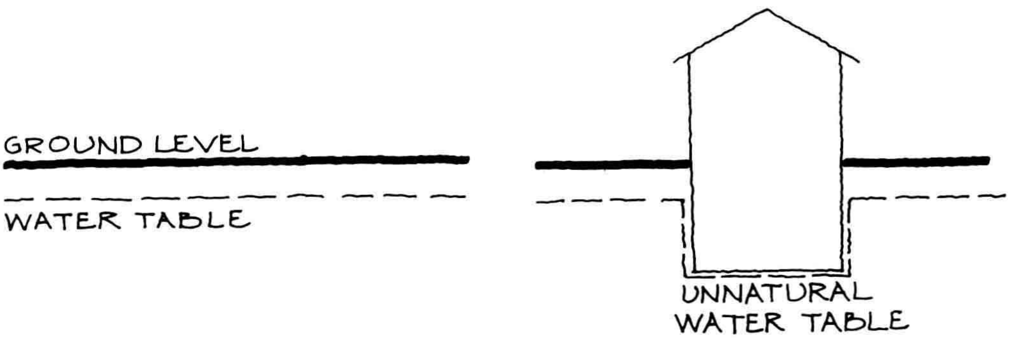


Fig.1.12

Not only are the walls loaded by the water pressure but it also causes **upward** loads on the floor. The building is trying to **float**!

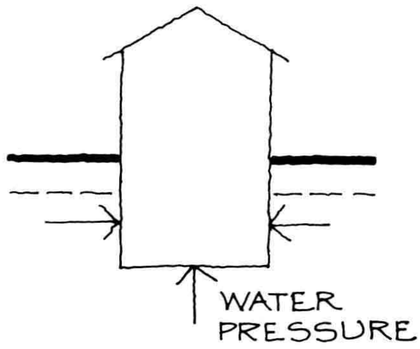


Fig.1.13

The structure has to resist natural loads due to **water pressure**.

The general shape of the surface of the Earth is sensibly the same over the life-span of most buildings, but may alter slightly due to climatic or geological changes. As the building is attached to the surface of the Earth, local changes will force a change in the shape of the structure, as the building is hardly likely to prevent the Earth changing shape! In particular, load may be caused if the local shape changes differentially. It is **not obvious** how this causes a load on the structure, if indeed it does. For example, suppose the plank bridge has a support in the stream.

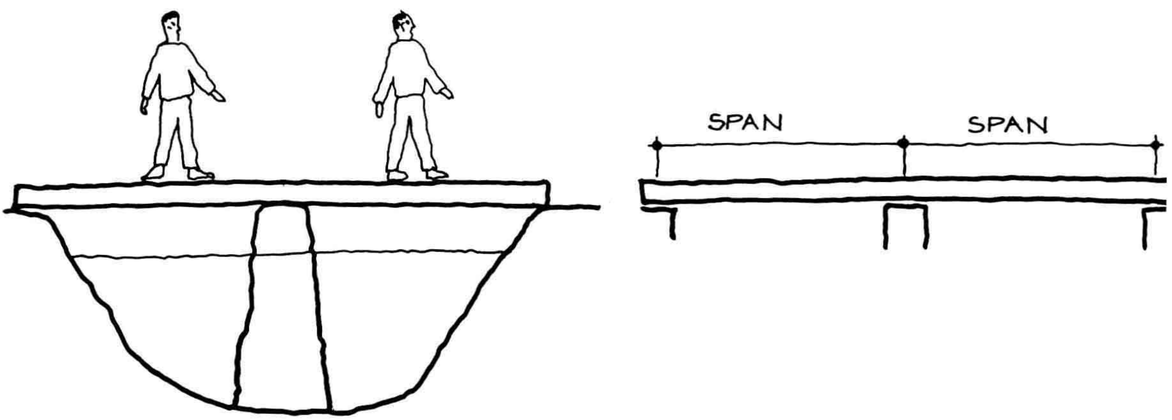


Fig.1.14

If this central support were to sink into the stream bed, depending on the fixing, it may pull the plank down (load it) or cease to be a support at all!

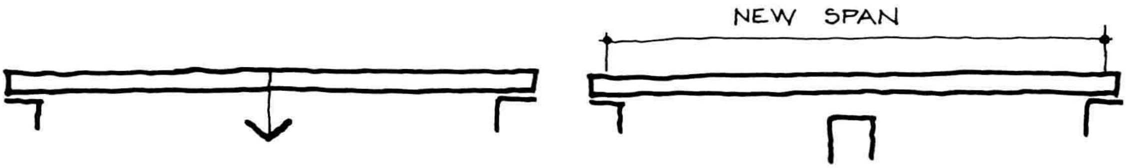


Fig.1.15

So **ground movements** can alter the load-carrying behaviour of a structure, and so be considered, in a rather roundabout way, to load the structure.

Another form of ground movement that can load a structure is an earthquake. Earthquakes are caused by sudden internal movements within the Earth's crust. This causes a shock to the system and results in shaking the crust of the Earth over a certain area. The earth's surface will both bounce up and down and move backwards and forwards.

Fig.1.16

In general the vertical movement is small compared to the horizontal movement. A building, during an earthquake, undergoes an experience similar to a person standing unaided on a cakewalk.

Fig.1.17