# CHAPTER 1

# INTRODUCTION

## 1.1 General

The issue of upgrading the existing civil engineering infrastructure has been one of great importance for over 20 years or so. Deterioration of bridge decks, beams, girders and columns, buildings, parking structures and others may be attributed to ageing, environmentally induced degradation, poor initial design and/or construction, lack of maintenance, and to accidental events such as earthquakes. The infrastructure's increasing decay is frequently combined with the need for upgrading so that structures can meet more stringent design requirements (e.g. increased traffic volumes in bridges exceeding the initial design loads), and hence the aspect of civil engineering infrastructure renewal has received considerable attention over the past few years throughout the world. At the same time, seismic retrofit has become at least equally important, especially in areas of high seismic risk.

Recent developments related to materials, methods and techniques for structural strengthening and seismic retrofitting have been enormous. One of today's state-of-the-art techniques is the use of **fiber reinforced polymer** (FRP) materials or simply **composites**, which are currently viewed by structural engineers as "new" and highly promising materials in the construction industry. Composite materials for strengthening of civil engineering structures are available today mainly in the form of: (a) thin unidirectional *strips* (with thickness in the order of 1 mm) made by pultrusion, (b) flexible *sheets* or *fabrics*, made of fibers in one or at least two different directions, respectively (and sometimes pre-impregnated with resin). Central to the understanding of composites bonded to concrete is the fact that stresses in these materials are carried only by the fibers, in the respective directions.

The reasons why composites are increasingly used as strengthening materials may be summarized as follows: immunity to corrosion; low weight (about ¼ of steel), resulting in easier application in confined space, elimination of the need for scaffolding and reduction in labor costs; very high tensile strength (both static and long-term, for certain types of FRP materials); stiffness which may be tailored to the design requirements; large deformation capacity, which results in substantial member ductility; and practically unlimited availability in FRP sizes and FRP geometry and dimensions. Composites suffer from certain disadvantages too, which are not to be neglected by engineers:

contrary to steel, which behaves in an elastoplastic manner, composites in general are linear elastic to failure (although the latter occurs at large strains) without any yielding or plastic deformation, leading to reduced (but generally adequate) ductility. Additionally, the cost of materials on a weight basis is several times higher than that for steel (but when cost comparisons are made on a strength basis, they become less unfavorable). Moreover, some FRP materials, e.g. carbon and aramid, have incompatible thermal expansion coefficients with conventional materials, such as concrete and masonry. Finally, their exposure to high temperatures (e.g. in case of fire) may cause premature degradation and collapse (some epoxy resins start softening at about 50-70 $^{o}$C). Hence FRP materials should not be thought of as a blind replacement of steel (or other materials) in structural intervention applications. Instead, the advantages offered by them should be evaluated against potential drawbacks, and final decisions regarding their use should be based on consideration of several factors, including not only mechanical performance aspects, but also constructability and long-term durability.

Composites have found their way as strengthening materials of reinforced concrete (RC) members (such as beams, slabs, columns etc.) and unreinforced masonry in many thousands of applications worldwide, where conventional strengthening techniques may be problematic (e.g. steel plating, steel jacketing, RC jacketing). For instance, one of the popular techniques for upgrading RC elements has traditionally involved the use of steel plates epoxy-bonded to the external surfaces (e.g. tension zones) of beams and slabs. This technique is simple and effective as far as both cost and mechanical performance is concerned, but suffers from several disadvantages (Meier 1987): corrosion of the steel plates resulting in bond deterioration; difficulty in manipulating heavy steel plates in tight construction sites; need for scaffolding; and limitation in available plate lengths (which are required in case of flexural strengthening of long girders), resulting in the need for joints. Replacing the steel plates with FRP strips provides satisfactory solutions to the problems described above. Another common technique for the strengthening of RC structures involves the construction of reinforced concrete (either cast in-place or shotcrete) jackets (shells) around existing elements. Jacketing is clearly quite effective as far as strength, stiffness and ductility is concerned, but it is labor intensive, it often causes disruption of occupancy and it provides RC members and/or masonry structures, in many cases, with undesirable weight and stiffness increase. Jackets may also be made of steel; but in this case protection from corrosion is a major issue, as is the rather poor confining characteristics of steel-jacketed concrete (or masonry). The conventional jackets may be replaced with FRP in the form of sheets or fabrics wrapped around RC members, thus providing substantial increase in strength (axial, flexural, shear, torsional) and ductility without much affecting the stiffness.

## 1.2 Structure of the book

In this document the aim is to give an overview of the main applications of composites as externally bonded reinforcement (EBR) of concrete and masonry structures and to present guidelines for design. Following a general description of materials and techniques related to the application of composites as external reinforcement of concrete and masonry in Chapter 2, the document contains several chapters, with each of them devoted to one particular aspect of strengthening with externally bonded FRP. Chapter 3 deals with the basis of design with FRP and the three following chapters deal with the design and structural behavior of concrete members strengthened in *flexure* (Chapter4), *shear* (Chapter 5) as well as through *confinement* (Chapter 6). Naturally, these chapters are followed by *detailing and practical execution rules* (Chapter 7). Chapter 8 describes general principles for the strengthening of unreinforced masonry walls with composites and Chapter 9 presents the pertinent design equations for in-plane loading, out-of-plane loading as well as confinement. Finally, Chapter 10 covers issues related to the long-term behavior of composites in structural interventions.