Innovative Grid Shell Structures in Fibre Reinforced Polymer Composites

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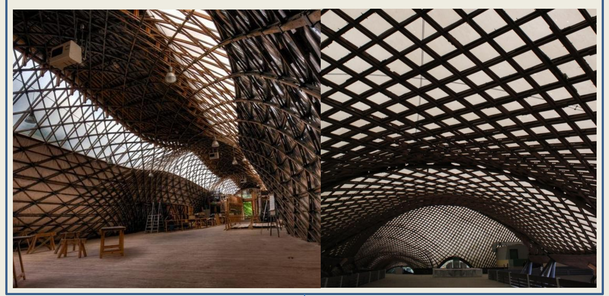
1 - Introduction

•Very elegant way to span large area with a very low material use
•Very sustainable construction method
•Typically made of timber and sometimes steel
•Numerous disadvantages with steel and timber grid shells
•Prudent to investigate possibility of a material that will address the disadvantages



2 – Aim of project

•To determine if it is feasible to construct grid shells from fibre reinforced polymers
•To determine if FRPs are more suitable than timber and steel

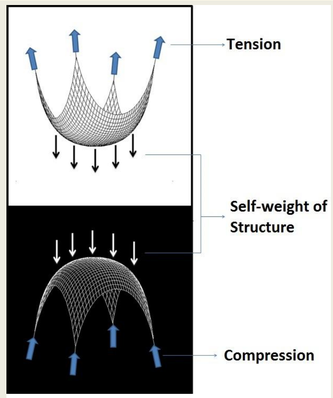
3 – Approach

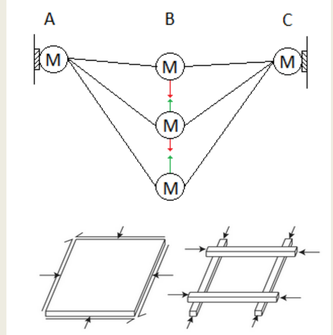
•Perform literature review to determine proceed with the task
- ➢Uses of grid shell structures
- ➢How grid shells behave structurally
- ➢How grid shells are designed
- ➢Shortcomings of current materials
- ➢Potential for FRPs
- ➢Long term loading effects on FRPs
- ➢Perform a case study on a current grid shell structure

•Short and long term load tests to determine creep behaviour
•Validation of modelling technique using existing projects to compare results
•Structural design and analysis of three different grid shells
•Develop design parameters based upon results of research and experiments

4 – Findings

•Grid shells shape is determined by a process called form finding
•Finds the shape in which the structure is in static equilibrium with its own mass
•In this position there are only axial loads within the structure
•Classic method of carrying out form finding used hanging chains representing the mass and stiffness of the chosen material
•More recently computation methods have been developed, such as dynamic relaxation
•Dynamic relaxation lumps virtual mass at the nodes of the grid, which is traced though small time increments until the residual force from the mass is equal to zero
•Grid shells start as flat lattice, that is deformed until the form found shape is reached
•Initially its strength is provided via compressive and bending forces in the lathes
•Diagonal reinforcement can be used to strengthen the structure in bending and reduce deflections
•Can be either single layered or double layered the latter providing similar strength but a greatly enhanced stiffness





•Long term testing of small samples can be used to predict full size behaviour
•Characteristics of steel and timber grid shells:

Material			
Timber		Steel	
Advantages	Disadvantages	Advantages	Disadvantages
Easy to deform	Imperfections	High strength	Hard to deform
Lightweight	Prone to attack	Resistant to attack	Heavy
	Low rupture strength		large temporary works
	Limited member size		site welding needed
	Properties change with humidity		

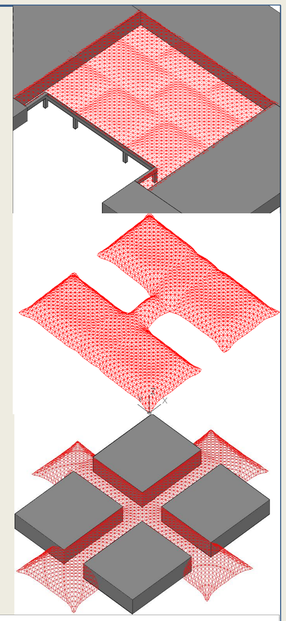
•FRPs have all of the advantages of both, and the disadvantages of neither, the only disadvantage being initial cost

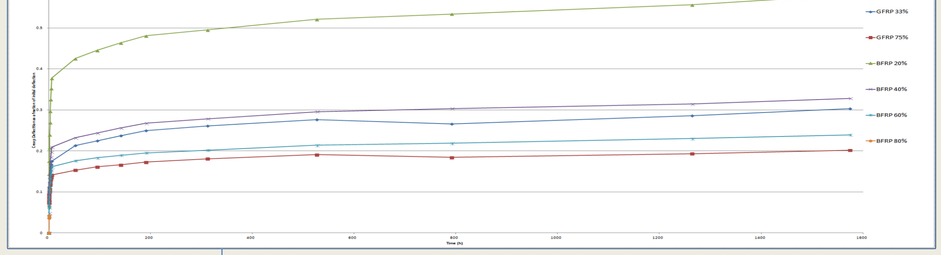
5 – Modelling

•Two structures from different papers modelled in Oasys (an FEA package by ARUP) to verify methodology
•Short term flexural tests carried out on samples of BFRP and GFRP to ascertain ultimate stress
•Long term flexural creep tests at varying percentages of ultimate stress tests to discover long term loading effects
•Creep results used to propose a ULS design method for FRP grid shell
•Upon verification three different grid shell structures designed to showcase the application of FRPs to create innovative grid shell structures

6 – Analysis

•Roof structure over excavation for a shopping centre (span/section ratio of 430.77)
•Exhibition centre (span/section ratio of 333.33)
•Roof over a street to create enclosed area for shops (span/section ratio of 266.66)
•Mannheim grid shell span/section ratio of 400, conventional structures between 11 and 40
•Tested for compression, buckling, bending, combined axial and compression, global buckling and deflection
•All three passed strength tests
•Problems with serviceability limit state requirements, quite large deflections
•Long term flexural tests show FRPs much more suitable than timber, and exhibit rapid elastic reformation after load removed
•For grid shells in general it was found that providing bracing between nodes has a huge impact in reduction of deflections and axial forces





7 – Conclusion

•It is concluded that it is indeed possible, and preferable to construct grid shells from FRP composites due to:
- ➢High strength
- ➢Suitable elasticity
- ➢Creep performance
- ➢Sustainability
- ➢Potential for higher span/section ratios

•Only problem encountered was too much deflection at mid span
•Deflection problem can be overcome via a variety of methods

8– Further study

• Multiple layer grid shells, to test the effect of multiple layers on total span potential
• Grid optimisation, form find other grid configurations than orthogonal, using GA optimisation techniques
• Different types of FRP
• Creep in different temperatures to test creep in a wide range of environments
•Study into the effects of global buckling of grid shells
•Different types of section
•Different construction methods
•Effects of accidental and exceptional loads
•Studies into precise imposed loads