Course unit title	***DESIGN FOR FIRE AND ROBUSTNESS***
Course unit code	2C10
Type of course unit	Compulsory
Semester	2
Number of ECTS credits allocated	6
Name of lecturer(s)	Zdeněk SOKOL , František WALD (CTU); Lecturer (UC); Lecturer (UNINA); Lecturer (UPT); Lecturer (ULg); Lecturer (LTU); Lecturer(Associate 1); Lecturer (Associate2).
Learning outcomes of the course unit	**Aim** The aim of this course is to give students an understanding of the design methods of structures at accidental situations, fire and explosion. The course is focussed on all design methods involved in fire design: prediction of fire scenario, evaluation of fire load, calculation of gas temperatures in the fire compartment and structural analysis. Special attention is paid to fire modelling when several design models is presented including nominal temperature curves, simple models and advanced models. Gas temperature in the fire compartment is considered as basis for the structural design. Methods for prediction of temperature of the structural elements are presented and mechanical properties of structural materials (steel, concrete, timber and aluminium structures) are presented. Design models for steel, concrete, steel concrete composite, timber and aluminium structural elements loaded by tension, compression and bending moment are presented. Attention is paid to protection of steel and timber structures to fire, various methods of protection are described. Smaller part of the course is focussed on explosions. Types of explosions are described together with design models. Basic principles of structural analysis are presented. Design methods are explained with focus to increase robustness of the structure. The theoretical part is supplemented with practical exercises using simple design models with aim to apply the knowledge in design of simple structural elements. Understanding of basic principles of structural analysis and design of steel, concrete and timber structures is necessary. **Skills** The course is conceived in order to give students following skills:

	- To understand the basic methods in fire engineering. - To be able to develop possible fire scenarios and to understand various fire models. - To predict the gas temperature in the fire compartment for the selected fire scenarios, to evaluate the fire load density and other fire parameters necessary for thermal analysis of the fire compartment. - To be able to predict temperature of unprotected and protected structural elements and to be able to select / design suitable fire protection of those elements. - To understand the specific problems related to structural analysis at fire. To be able to predict the mechanical load at fire and calculate internal forces of simple structures exposed to fire. - To understand the effect of high temperature on mechanical properties of steel, concrete, timber and aluminium alloys. To be able to design steel, concrete, steel-concrete composite, timber and aluminium structures exposed to fire. - To understand the purpose of fire testing, measurements and equipment of fire testing laboratory, large scale testing. - To understand the models for load by explosion in open and closed space, structural analysis at explosion, structural damages and repair of structures. - To understand the robustness of structures and to be able to design simple structures to ensure structural integrity.
Mode of delivery	Frontal lessons, seminar k and home work
Prerequisites and co-requisites	No requirements
Course contents	Thermal analysis of the fire compartment, including prediction of possible fire scenarios, evaluation of fire load density, rate of heat release and other parametres necessary for the analysis represent the most important part of the fire design procedure and are the main part of the course. It will be focussed on various design methods of prediction of gas temperature in the fire compartment. Simple methods (nominal and parametric fire curves) and advanced methods (localised fire, zone models) will be described in details, overview of CFD will be given. Several useful software tools for easy application of these models will be presented. Prediction of structural behaviour and mechanical load during the fire follow the thermal analysis. Students should be able to predict temperature and resistance of steel, concrete, steel concrete composite, timber and aluminium structural elements. This will be

	documented on simple elements such as beams and columns and complex structures (steel frame). The students practise the design methods according to European standards to be able to perform structural design at fire. The students should understand different types of explosion, evaluation of parametres of the explosion and dynamic analysis of the structures. Basic principles of robustness of the structure, structural design to increase robustness and to prevent progressive collapse of the structure will be explained. This will be demonstrated on some existing buildings. Practical application (evaluation of joint tying capacity) will be practised by students.
Recommended or required reading	Jean-Marc Franssen J.M., Vila Real P., Fire Design of Steel Structures, ECCS, Publication 302, ISBN 978-92-9147-099-0. Buchanan A. H., Structural Design for Fire Safety, John Wiley and Sons, Chichester 2003. ASCE Manual, Performance-Based Design of Structural Steel for Fire Conditions, American Society of Civil Engineers, 2009. Lennon T., Moore D.B., Wang Y.C., Bailey G.G., Designer's Guide to EN 1991-1-2, EN 1992-1-2, EN 1993-1-2 and EN 1994-1-2, Thomas Telford, 2006. Access Steel website (ww.access-steel.com).
Planned learning activities and teaching methods	Eleven topics, listed below are covered in the course. **1 Introduction to fire safety** 1.1 - Fire safety, classification of structures, fire compartments, escape routes (general overview) 1.2 - Natural fire and its relation to design to fire safety **2 Fire load and models of fire** 2.1 - Fire load density, characteristic and design load, effect of active fire measures, rate of heat release, fire scenarios 2.2 – Simple models for compartment fires, nominal fire curves, parametric temperature curve Practical calculation of fire load density for simple compartment, evaluation of temperature curve, comparison of different models, advantages and disadvantages of simple models 2.3 - Advanced fire for compartment fires, zone models, CFD models Application of software to apply zone models for thermal analysis, overview of CFD analysis 2.4 - Fire load for localised fires, modelling of localised fires **3 Structural analysis at fire** 3.1 - Accidental load combination, structural analysis at fire 3.2 - Video from large scale fire test in Cardington, example of analysis of steel structure in Cardington

4 Fire resistance of steel structures

4.1 - Temperature of unprotected steel elements at fire, fire protection of steel structures, temperature of protected steel elements at fire

4.2 - Material properties of steel at high temperatures

4.3 - Resistance of element loaded in tension, compression, bending, lateral torsional stability of beams

4.4 - Design of joints

Practical application: design of simple elements exposed to fire: unprotected beam, protected column

5 Fire resistance of concrete structures

5.1 - Material properties of concrete at high temperatures

5.2 - Resistance of reinforced concrete slabs, beams and columns

Tables, simple methods, advanced methods

Practical application: design of simple elements exposed to fire: concrete beam, concrete column

6 Fire resistance of steel concrete composite structures

6.1 - Fire resistance of composite slab

6.2 - Resistance of composite beams

Tables, simple methods, software AFCB

6.3 - Resistance of composite columns

Tables, simple methods, software AFCC

Practical application: design of simple elements exposed to fire: composite beam, composite column

7 Fire resistance of timber structures

7.1 - Behaviour of timber structures exposed to fire, fire protection of timber structures

7.2 - Design method for timber structures

Method of effective cross-section, method of reduced stiffness and strength

7.3 - Design of joints

Practical application: design of simple elements exposed to fire: timber beam, timber column

8 Fire resistance of aluminium structures

8.1 - Temperature of aluminium structures exposed to fire,

8.2 - Material properties of aluminium alloys exposed to high temperatures

8.3 - Resistance of elements loaded by tension, compression and bending moment

9 Fire tests

9.1 - Introduction to testing and measurement, equipment of fire test laboratory, examples of tests, test setup

	9.2 - Large scale fire tests (Cardington, Mokrsko), evaluation of test data **10 Loading at and structural analysis at explosion** 10.1 - Types of explosion, explosion in enclosed open and space, interaction with buildings, structural analysis at explosion, 10.2 - Mechanical behaviour of material at dynamic load. 10.3 - Damage to structures, protection of structures to explosion, reconstruction **11 Robustness** 11.1 - Design for robustness, structural behaviour, structural integrity, ductility **Project assignment** Fire resistance of steel / composite / timber building - defining fire scenarios, evaluation of fire parametres, thermal analysis, temperature of structural elements and evaluation of fire resistance according to requirements, design of fire protection when necessary - various structures can be covered: office buildings, car parks, industrial buildings of various purpose, storage buildings, shopping centres, etc.
Assessment methods and criteria	Approved assignments will be necessary to prepare at the end of the course on the work performed during the course. Grading system. Passed or not passed. A certificate awarding ECCS credits may be provided upon the request.
Language of instruction	English