UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Mehanika lahkih struktur
Course title:	Mechanics of light-weight structures
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Mehanika (smer)	2. letnik	1. semester

Univerzitetna koda predmeta/University course code:	0566904
Koda učne enote na članici/UL Member course code:	6040-M

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Miha Brojan
Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Mehanika, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Mechanics, which is an elective specialised course in other fields of study.

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisites:**
Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina:	**Content (Syllabus outline):**
1. Vsebina 1. Predavanja - Seznanitev s študijskimi pravili in obveznostmi - Predstavitev študijske literature - Pregled celotne vsebine predavanj - Osnovne goemetrijske lastnosti lahkih struktur 2. Vsebina 2. Predavanja	1. Topics of Lecture 1 - Definition of rules and obligations for following and completing the course - Presentation of relevant study literature - Complete overview of course topics - Basic geometric properties of lightweight

- Učinkovita izraba materiala, ugodna porazdelitev napetosti v lahkih konstrukcijah (primerjave zgradb iz biologije)
- Pregled vitkih (tankostenskih) konstrukcijskih elementov: nosilec, plošča, lupina
- Kompozitna struktura

3. Vsebina 3. Predavanja
   - Problematika uporabe vitkih elementov (nezveznosti, nelinearnosti, imperfekcije, medsebojni vpliv povezanih elementov, stabilnost)
4. Vsebina 4. Predavanja
   - Osnovni pojmi stabilnosti konstrukcij, določitev stabilnostih razmer v vitkih strukturah
5. Vsebina 5. Predavanja
   - Limitna obtežba (preskok sistema), bifurkacija (primer: tog drog)
   - (Fizikalno pravilno) ravnovesje na deformiranem nosilcu
6. Vsebina 6. Predavanja
   - Eulerjev uklon
   - Uklon imperfektnih nosilcev (geometrijske in obremenitvene imperfekcije)
7. Vsebina 7. Predavanja
   - Uklon pod vplivom lastne teže
   - Elastično vpetje
8. Vsebina 8. Predavanja
   - Nosilec na elastični podlagi, gubanje
9. Vsebina 9. Predavanja
   - Uklon realnega elasto-plastičnega nosilca
   - Zvrnitev konzole (uklon stojine pri upogibu I-profila)
10. Vsebina 10. Predavanja
    - Izboljšanje nosilnosti s pomočjo optimizacije
    - Definicija optimizacijskega problema (ciljna funkcija, enakostne in neenakostne vezi, Karush-Kuhn-Tuckerjev izrek)
11. Vsebina 11. Predavanja
    - Enostavni primeri optimizacije
    - Optimizacija nosilnosti kompozitnega nosilca na primeru letalskega krila
12. Vsebina 12. Predavanja
    - (Fizikalno pravilno) ravnovesje na deformirani plošči
    - Föppl-von-Karmanova teorija plošč 1. del
13. Vsebina 13. Predavanja
    - Föppl-von-Karmanova teorija plošč 2. del
    - Upogib elastične plošče
14. Vsebina 14. Predavanja
    - Upogib kompozitne plošče
15. Vsebina 15. Predavanja
    - Gubanje kompozitnih plošč

structures

2. Topics of Lecture 2
   - Efficient material use, favourable stress distribution in lightweight structures (comparison with biological structures)
   - Review of slender (thin-walled) structural elements: beam, plate, shells
   - Composite structure
3. Topics of Lecture 3
   - Problems of slender element application (discontinuities, nonlinearities, imperfections, interactions of connected elements, stability)
4. Topics of Lecture 4
   - Basic concepts of stability of structures, determination of stability conditions in slender structures
5. Topics of Lecture 5
   - Limit point load (snap-throug), bifurcation (example: rigid bar)
   - (Physically correct) equilibrium on the deformed beam
6. Topics of Lecture 6
   - Euler buckling
   - Buckling of imperfect beams (geometric and loading imperfectioncs)
7. Topics of Lecture 7
   - Buckling of a bar under self-weight
   - Elastic support
8. Topics of Lecture 8
   - Beam on an elastic foundation, wrinkling
9. Topics of Lecture 9
   - Buckling of real-life elastic-plastic beam
   - Torsional buckling (bukling of a web in an I-beam)
10. Topics of Lecture 10
    - Improving load-carrying capacity by optimization
    - Definition of an optimization problem (objective function, equality and inequality contitions, Karush-Kuhn-Tucker theorem)
11. Topics of Lecture 11
    - Simple cases in optimizaion
    - Optimizatiojn of load-carrying capacity of a composite beam (aircraft wing)
12. Topics of Lecture 12
    - (Physically correct) equilibrium on a deformed plate
    - Föppl-von-Karman plate theory, part 1
13. Topics of Lecture 13
    - Föppl-von-Karman plate theory, part 2
    - Bending of an elastic plate
14. Topics of Lecture 14
    - Bending of a composite plate
15. Topics of Lecture 15

	- Wrinkling of compostite plates

Temeljna literatura in viri/Readings:

1. S.P. Timoshenko, J.M. Gere: Theory of Elastic Stability, Dover Publications, 2009.
2. G. Simitses & D.H. Hodges: Fundamentals of Structural Stability, Butterworth-Heinemann, 2006.
3. J.M.T. Thompson & G. W. Hunt: General Theory of Elastic Stability, Wiley, 1973.
4. J. Singer, J. Arbocz, T. Weller: Basic Concepts, Columns, Beams and Plates (Volume 1 & 2), Wiley, 1998.
5. D. Bigoni: Nonlinear Solid Mechanics – Bifurcation Theory and Material, Cambridge University Press, 2014.
6. Z.P. Bazant, L. Cedolin: Stability of Structures: Elastic, Inelastic, Fracture, and Damage Theories, WSPC, 2010.
7. J.S. Arora: Introduction to Optimum Design 4th Edition, 2016
8. R.M. Jones: Mechanics of Composite Materials, CRC Press, 1998.
9. E.G. Wolff: Introduction to the Dimensional Stability of Composite Materials, Destech Publications, 2004.
10. S. Akbarov: Stability Loss and Buckling Delamination: Three-Dimensional Linearized Approach for Elastic and Viscoelastic Composites, Springer, 2013.
11. G.Z. Voyiadjis: Mechanics of Composite Materials with MATLAB, Springer, 2005.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Naučiti se osnov nealinearne mehanike konstrukcijskih elementov 2. Naučiti se koristno uporabiti (ne)stabilnostne pojave za napredne funkcionalnosti 3. Naučiti se snovanja lahkih konstrukcij za učinkovito izrabo materiala Kompetence: 1. S7-MAG + P3-MAG: Sposobnost uporabe nelienarne mehanike za preračun konstrukcijskih elementov 2. S2-MAG + P2-MAG: Sposobnost snovanja sistemov z naprednimi funkcionalnostmi 3. S1-MAG + P4-MAG: Sposobnost snovanja lahkih konstrukcij z učinkovito izrabo materiala	Goals: 1. Learn the basics of nonlinear mechanics of structural elements 2. Learn to take advantage of instabilites for advanced functionality 3. Learn to design light-weight structures for efficient material use Competences: 1. S7-MAG + P3-MAG: Ability to understand the basics of nonlinear mechanics of structural elements 2. S2-MAG + P2-MAG: Ability to take advantage of instabilites for advanced functionality 3. S1-MAG + P4-MAG: Ability to design light-weight structures for efficient material use

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z1: Poglobljeno strokovno teoretično in praktično znanje na določenem področju, podprto s širšo teoretično in metodološko osnovo. • Poglobljeno znanje o nelinearnem odzivu konstrukcijskih elementov	Knowledge: Z1: Thorough professional theoretical and practical knowledge in a selected field of expertise that is supported with a broad theoretical and methodological basis. • In-depth knowledge of nonlinar response of

- Poglobljeno poznavanje mehanike kompozitnih struktur
- Poglobljeno znanje o metodah reševanja nelinearnih problemov za gradnjo lahkih struktur

Spretnosti:

S1.1 Izvajanje kompleksnih operativno-strokovnih opravil, ki vključujejo tudi uporabo metodoloških orodij.

- Določitev nelinearnega mehanskega odziva vitkih elementov
- Določitev kritičnih notranjih obremenitev v vitkih konstrukcijskih elementih
- Dimenzioniranje lahkih kompozitnih elementov

structural elements
- In-depth understanding of mechanics of composite structures
- In-depth understanding of solution methods of nonlinear problems for the design of light-weight structures

Skills:

S1.1 Executing complex operationa-professional tasks that incorporate usage of methodological tools.

- Determination of nonlinear response of slender elements
- Determination of critical inner loads in slender structural elements
- Design of light-weight composite elements

Metode poučevanja in učenja:

Klasične oblike poučevanja:

1. P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.

2. P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki.

3. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri.

4. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki

- Eksperimentalna naprava za spremljanje upogibnih deformacij
- Trgalni stroj
- Simulacija preskoka sistema z vzmetmi
- Eksperiment v vakuumski komori
- Eksperimentalna priprava za prikaz tlačno-volumske karakteristike tankih zaprtih lupin

5. P5 Uporaba študijskega gradiva v obliki

- E-domače naloge
- E-zapiski
- Tiskana verzija

Moderne in prožne oblike poučevanja:

1. P6 Interaktivna predavanja
2. P7 Študij literature in razprava
3. P9 Skupinsko delo (razprave za – proti, razprave o prebranem)

Nekaj primerov uporabe IKT:

1. P12 Individualizirane domače naloge
2. P14 Virtualni eksperimenti (FEM simulacije)
3. P15 Uporaba video vsebin kot priprava na predavanja in vaje

Learning and teaching methods:

Conventional teaching methods:

1. P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases.

2. P2 Presenting the content according to the explained system.

3. P3 Auditorial exrecises, in which theoretical content from the lectures is supplemented with practical examples.

4. P4 Laboratory exercises with special-purpose didactic devices

- Experimental apparatus for the analysis of beam bending
- Tensile testing machine
- Vacuum chamber experiments
- Experimental apparatus for the analysis of pressure-volume relation in pressure vessels

5. P5 Application of study material

- E-homework
- E-manuscripts
- Printed versions

Contemporary and flexible teaching methods:

1. P6 Interactive lectures
2. P7 Literature study and discussion
3. P9 Team work (discussion pro and contra, discussion of the studied content)

Some cases of ICT usage:

1. P12 Individualised homeworkes in a web classroom
2. P14 Virtual experiments (FEM simulations)
3. P15 Application of videos for preparations to the lectures and exercises

Načini ocenjevanja:	Delež/Weight	Assessment:
Izpit (predavanja – teorija)	60,00 %	Examination (lectures - theory)
Izpit (vaje – naloge, prepračuni)	20,00 %	Examination (exercises – design calculations)
Laboratorijske vaje	10,00 %	Laboratory exercises
Domača naloga	10,00 %	Homework

Reference nosilca/Lecturer's references:

Miha Brojan

1. VELDIN, Tomo, BRANK, Boštjan, BROJAN, Miha. Computational finite element model for surface wrinkling of shells on soft substrates. *Communications in Nonlinear Science & Numerical Simulation*, ISSN 1007-5704, maj 2019, letn. XX, str. 1-29, ilustr. https://doi.org/10.1016/j.cnsns.2019.104863, doi: 10.1016/j.cnsns.2019.104863. [COBISS.SI-ID 8813409], [JCR, SNIP, WoS do 20. 9. 2019: št. citatov (TC): 0, čistih citatov (CI): 0, Scopus do 24. 6. 2019: št. citatov (TC): 0, čistih citatov (CI): 0]
2. LAGRANGE, Romain, LÓPEZ JIMÉNEZ, F., TERWAGNE, Denis, BROJAN, Miha, REIS, Pedro. From wrinkling to global buckling of a ring on a curved substrate. *Journal of the mechanics and physics of solids*, ISSN 0022-5096. [Print ed.], Apr. 2016, vol. 89, str. 77-95, ilustr., doi: 10.1016/j.jmps.2016.02.004. [COBISS.SI-ID 14610203], [JCR, SNIP, WoS do 13. 10. 2019: št. citatov (TC): 12, čistih citatov (CI): 11, Scopus do 29. 8. 2019: št. citatov (TC): 11, čistih citatov (CI): 10]
3. BROJAN, Miha, KOSEL, Franc. Approximative formula for post-buckling analysis of nonlinearly elastic columns with superellipsoidal cross-section. *Journal of reinforced plastics and composites*, ISSN 0731-6844, 2011, vol. 30, iss. 5, str. 409-415, doi: 10.1177/0731684410397897. [COBISS.SI-ID 11694363], [JCR, SNIP, WoS do 21. 4. 2019: št. citatov (TC): 7, čistih citatov (CI): 5, Scopus do 24. 3. 2019: št. citatov (TC): 8, čistih citatov (CI): 6]
4. BROJAN, Miha, TERWAGNE, Denis, LAGRANGE, Romain, REIS, Pedro. Wrinkling of thin spherical shells on elastic substrates. V: *3rd Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures with DESICOS Workshop, 25-27 March 2015, Braunschweig, Germany : final program*. [S. l.: German Aerospace Center - DLR. 2015?], f. 45. [COBISS.SI-ID 13937691]
5. ČEBRON, Matjaž, BROJAN, Miha. *Analiza vpliva lonca motorja na karakteristiko centrifugalnih ventilatorjev s kolesi LTI : D310 in D400*. Ljubljana: Fakulteta za strojništvo, Laboratorij za nelinearno mehaniko, 2016. 19 f., graf. prikazi. [COBISS.SI-ID 14614299]