ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ

ΣΧΟΛΗ ΝΑΥΠΗΓΩΝ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

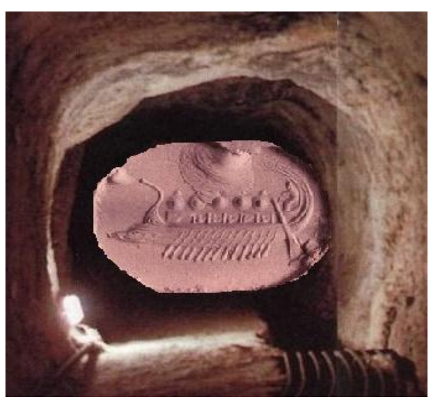
ΔΠΜΣ: "ΝΑΥΤΙΚΗ ΚΑΙ ΘΑΛΑΣΣΙΑ ΤΕΧΝΟΛΟΓΙΑ ΚΑΙ ΕΠΙΣΤΗΜΗ"

ΜΕΤΑΠΤΥΧΙΑΚΗ ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

ΘΕΜΑ: "ΔΥΝΑΜΙΚΗ ΑΛΛΗΛΕΠΙΔΡΑΣΗ ΛΕΠΤΟΓΡΑΜΜΩΝ ΘΑΛΑΣΣΙΩΝ ΑΓΩΓΩΝ ΜΕ ΤΟΝ ΠΥΘΜΕΝΑ"

Φοιτητής: Κατηφέογλου Στέφανος

Επιβλ. καθηγητής: Ιωάννης Χατζηγεωργίου



ΑΘΗΝΑ, ΙΟΥΛΙΟΣ 2011

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

ƱΆΛΗΕΧΟΜΕΝΑ

[illegible]

[illegible] - Riser (Steel Catenary Riser) [illegible] riser [illegible] riser [illegible] "sagbend" [illegible] riser [illegible] -Touch Down Point/TDP- [illegible] riser [illegible]

[illegible] riser [illegible] Phase2. [illegible] TDP [illegible] riser [illegible] TDP [illegible]

[illegible]: "*Three dimensional nonlinear dynamics of submerged, extensible catenary pipes conveying fluid and subjected to end-imposed excitations*" [7].

[illegible] Phase2, [illegible] Rocscience, [illegible], [illegible], [illegible], [illegible].

ABSTRACT

In the present thesis, an effort has been made for quantification of the effect of soil reaction in the motion of a slender Steel Catenary Riser structure -used for the transport of hydrocarbons from offshore fields- and, sequentially, import of the defined values of soil reaction forces to a published nonlinear dynamic model of Finite Differences that identifies the dominating dynamic parameters of the induced motion of the Riser due to harmonic excitations applied on the top end of the structure (e.g. harmonic wave-induced movements of the floating platform which binds the riser, etc). Based on observations of the contemporary international research, such harmonic moves are, by definition, the major sources of fatigue damage, especially at the most vulnerable area "sagbend" (the area of the riser before the Touch Down Point / TDP - up to it) exhibiting the maximum curvature, and are the fundamental causes for trench formations created at the surface of the bottom due to consequent movements of the lower section of the riser, the bottom laying part.

The determination of the soil reaction is static, assuming that the riser has completed the cycle of embedment in the soil, for various penetration depths and various excavation geometries, as well, based on previously published experimental observations. At first, the plain stress condition of the soil, for all cases of penetration depths and trench formations, is accomplished with the contribution of the Geotechnical, commercial software, Phase2. Then the stresses are integrated around the arched riser-soil contact surface for the production of vertical soil-reacting forces in the penetration of the riser, for each case of the examined trench formations, as well. Finally, these force-values are imported as concentrated loads applied at the TDP, in the existing nonlinear dynamic model, which is then solved for various cases of harmonic excitations applied on top of the riser, in order to test the effect of TDP soil reaction in the various dynamic parameters involved in fatigue damage.

The non-linear dynamic model has been published on the work of Assoc. Prof. I. Chatjigeorgiou: "*Three dimensional nonlinear dynamics of submerged, extensible catenary pipes conveying fluid and subjected to end-imposed excitations*" [7]. The Geotechnical Code, Phase2, by Rocscience, is a property of the Laboratory of Structural Engineering and Elements of Structures, School of Rural and Surveying Engineering, NTUA, chaired by Professor Michael Sakellariou, who provided it for all necessary calculations.

1. [illegible]

[illegible] Steel Catenary Risers (SCR). [illegible] SCR. [illegible] 1500 [illegible] 3.000 [illegible].

[illegible] SCR [illegible] SCR [illegible] - SCR system, [illegible].

[illegible] riser [illegible] TDP (Touch Down Point). [illegible] [12, 15, 46].

[illegible] riser [illegible].

[illegible] (Phase 2).

[illegible]

[illegible] [7], [illegible] "in-plane", [illegible] z, [illegible]).

1.1 [illegible] SCR.

[illegible] *(*[illegible]*: drill-ship)* ***[illegible]***[10].

[illegible] SCR [illegible] [10]. [illegible] (buckling) [illegible] (FEM), [illegible]

1.2 [illegible] riser [illegible]

[illegible] 20 [illegible] riser- [illegible]

[illegible]

[illegible] Bridge et al. [33], [illegible] 2001 [illegible] 2003, [illegible] riser- [illegible]

- [illegible]
- [illegible]
- [illegible] (scour) [illegible]
- [illegible] "Vortex Induced Vibrations" [illegible]

- [illegible] (*ñlift forceò* + [illegible]) [illegible].

[illegible] Aubeny et al. [2, 4] [illegible] riser [illegible] (k) [illegible] [1, 3], [illegible].

[illegible] "[illegible] Euler - Bernoulli [illegible] Winkler)" [illegible] American Society of Civil Engineers (ASCE 2005) [illegible] ***ñstrip foot foundationsò*** [51] [illegible] "[illegible]" [illegible].

[illegible] Dendani, France and Jaeck [48], [illegible] 2008 [illegible] Norwegian Geotechnical Institute (2005), [illegible] riser [illegible] Hansen [46] [illegible] Terzaghi (1943) [illegible] Hansen, [illegible] Verley and Lund [47].

[illegible] risers [illegible] risers [illegible] Verley and Lund [47], [illegible] 1995. [illegible] risers [illegible] S-Lay [illegible] J-Lay [illegible] Hansen:

$$\frac{z_{init}}{D} = 0.0071(S*G^{0.3})^{3.2} + 0.062(S*G^{0.3})^{0.7}$$

[illegible] D [illegible] S [illegible] G [illegible] Su [illegible] Verley [illegible] Lund [illegible] 2000-2010 [54].

[illegible] Nakhaee and Zhang [5], [illegible] P-y [illegible] riser [illegible] riser [illegible] riser. [illegible] riser [illegible] riser - [illegible] TDZ (Touch Down Zone).

2. [illegible]

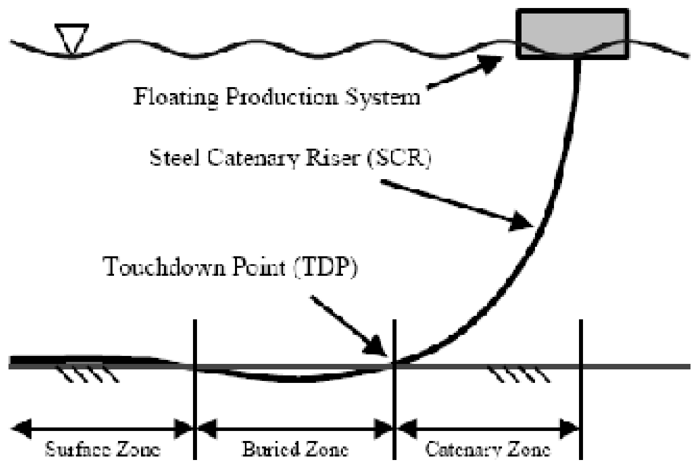
2.1 [illegible] riser [illegible]

[illegible]

[illegible] TDP ([illegible] riser [illegible]), [illegible] riser [illegible] riser ([illegible]) [illegible]

[illegible] riser, [illegible] riser "[illegible]" [illegible]

[illegible] riser, [illegible] (scour) [illegible] [9, 33] [illegible]

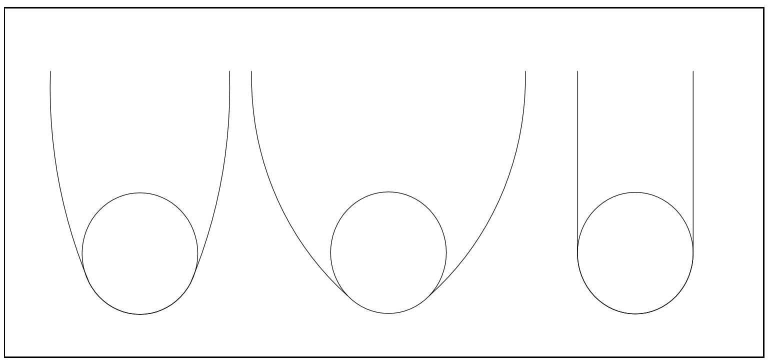


[illegible] 2.1: [illegible] riser ([illegible] : Bridge et al., 2003)

[illegible] riser [illegible] TDP, [illegible]

- ***[illegible]** riser **[illegible]** (*[illegible] 2.1) ***[illegible]*** [33]. [illegible] riser [illegible] 2 [illegible] TDP. [illegible] "buried zone" [illegible] "surface-zone".
- [illegible]

- [illegible] riser, [illegible] (heave motions) [illegible] (surge) [illegible] riser, [illegible] riser [illegible]
- [illegible] (2.2 [illegible]).



[illegible] 2.2: [illegible]

[illegible]

[illegible] riser [illegible] [10].

[illegible]

2.2 [illegible]

[illegible] riser [illegible] 2.2.).

[illegible] riser [illegible] riser [illegible] 2.1 [illegible]

$$F_{sr} = R\oint \sigma \sin \theta \mathrm{d}\theta$$

[illegible] Fsr [illegible] Phase 2 (Rocscience ltd.).

[illegible] riser [illegible] "CON3DF" [7] [illegible] Fortran. [illegible] x, [illegible] y [illegible] z [illegible]

[illegible] TDP, [illegible] (kN/m) [illegible] «CON3DF» [illegible].

[illegible] CON3DF [illegible] 4.

2.3 [illegible] riser [illegible]

[illegible] riser [illegible].

[illegible] "CON3DF".

[illegible] Phase 2, [illegible].

3. [illegible] Phase 2 - [illegible]

3.1 [illegible]

[illegible] ASTM (D 653): [illegible]

[illegible]

3.1.1. [illegible]

[illegible] «[illegible]» [illegible] USCS, [illegible] >300 mm [illegible] < 0.075 mm. [illegible] <0.002 mm.

[illegible]

[illegible]

3.1.2. ȸɟ ɘů ɛ ɏɜ Ǘɠ ű ɡůɘ ɏɠ ɘŭɘɧ Ǘɖ Ǘǘɠ ŮŭŬ ű ɩ ɜ ï Oɟ ɘů ɛ ɞɑ

- Ʉ Ǘɟ ɘǗɓɧ ɛ Ů ɜɖ ɡɔɟ Ŭůɑ Ŭ (w): ο ɘɧɔɞɠ % Ǘɞɡ ɓƳɟ ɞɡɠ Ǘɞɡ ´ Ǘɟ ɘǗɓɧ ɛ Ů ɜɞɡ ɜ Ǘɟ ɞɨ ů Ǘɞɡɠ ´ ɧɟ ɞɡɠ Ǘɞɡ ŮŭƳű ɞɡɠ (W_w) ´ ɟ ɞɠ Ǘɞ ɓƳɟ ɞɠ Ǘɤ ɜ ɜɖɟ ɩ ɜ ɘɧɘɘɤ ɜ Ǘɞɡ ŮŭƳű ɞɡɠ (W_s)

$$w\% = (W_w/W_s)\ 100$$

Ɇ Ǘǘ ´ Ǘɟ ɘůůɧǗǗɟ Ŭ ŮŭƳű ɖ ɘɡɛ Ŭɑ Ǘǘǘ ɛ Ǘǘǘ ɘɨ 0 ï 50%.

- ȸ Ŭɖ ɛ ɧɠ ɘɞɟ Ůű ɛ ɞɨ (s): ´ ɞůɞůǗɧ ɧɔɘɞɡ Ǘɤ ɜ ´ ɧɟ ɤ ɜ ´ ɞɡ ´ ɘɖɟ ɞɨ ɜ Ǘǘ ɘ ɛ Ů ɜǗɟ ɧ (V_w) ůŮů ɞɏ ů ɖ ɛ Ů Ǘɞ ů ɡɜ ɞɘɘɧ ɧɔɘɞ Ǘɤ ɜ ´ ɧɟ ɤ ɜ (V_v).

$$S = V_w / V_v$$

ȳ Ǘǘ ɜ Ǘɞ ɏŭ Ŭű ɞɠ Ůɑ Ŭ ɘ ´ ɘɐɟ ɤ ɠ ɘɞɟ Ůű ɛ ɏɜɞ, ɧ ´ ɤ ɠ ů Ǘɞ ɜ ɖ Ŭ ɘƳ ůů ɘ ´ ɡɖ ɛ ɏɜ Ŭ, ɖ Ǘɞ ɛ ɐ Ǘɞɡ Ůɑ Ŭ ɘ 1 (ɐ 100, Ŭ ɜ Ů ɘű ɟ Ƴɛ Ǘǘǘ ɘ %).

- ū Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ ($ɔ_b$): ɞ ɘɧɔɞɠ Ǘɞɡ ű ɡůɘ ɞɨ ɓƳɟ ɞɡɠ ŮŭŬű ɘɞɨ ŭŮɑ ɛ Ŭ Ǘɞɠ ´ ɟ ɞɠ Ǘɞ ůɡɜɞɘɘɧ Ǘɞɡ ɧɔɘɞ (ůǗǗɟ Ů ɜ ɘ Ŭ ɘ ɘ Ů ɜɩ ɜ). Ɇɡɜ Ŭ ɜ ǗƳ Ǘǘ ɘ ɘ Ŭ ɘ ɤ ɠ Ů ɘŭ ɘɧ ɓƳɟ ɞɠ, ɞƳɟ ɘ Ů ɧɘɞɘɖ Ŭ ɠ.

$$ɔ_b = W_t / V_t.$$

Ⱥű ɧůɞɜ Ů ɛ ´ Ǘɟ ɘɏɞ Ů ɘ ´ ɞůɞůǗɧ ɡɔɟ Ŭůɑ Ŭ ɠ ɞɜɞɛ Ƴɛ Ǘǘǘ ɘ ɡɔɟ ɧ ű Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ ($ɔ_g$).

- ʔ ɖɟ ɧ ű Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ ($ɔ_ɜ$): Ǘɞ ɑŭɘ ɛ Ů Ǘɞ $ɔ_b$, ɔɘŬ Ǘɖɜ ´ Ǘɟ ɑ Ǘɤ ůɖ, ɧ ɛ ɤ ɠ, ´ ɞɡ Ǘɞ ŭŮɑ ɛ Ŭ Ůɑ Ŭ ɘ ɜɖɟ ɧ, ɛ Ů ɛ ɖŭ Ů ɜɘɘɧ ´ ɞůɞůǗɧ ɡɔɟ Ŭůɑ Ŭ ɠ. Ⱥű ɧůɞɜ ɏɞ Ů ɘ ´ ɟ ɞůŭɘɟ ɘů Ǘǘ ɑ ɖ ɡɔɟ Ŭůɑ Ŭ ů Ů ɘ Ƴ ɞɘ ŭŮɑ ɛ Ŭ, ɖ ůɞɏ ů ɖ ´ ɞɡ ůɡɜ ŭɏ Ů ɘ Ǘɞ ɜɖɟ ɧ ű Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ ɛ Ů Ǘɞ ɡɔɟ ɧ ű Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ Ůɑ Ŭ ɘ ɖ Ŭ ɘɧɘɞɡɖɖ:

$$ɔ_g = ɔ_ɜ/(1+w)$$

- ū Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ 100% ɘɞɟ Ůű ɛ ɏɜɞɡ ŮŭƳű ɞɡɠ ($ɔ_{sat}$):

$$ɔ_{sat} = (W_s + W_w)/V_t$$

- Ɉ ´ ɧ Ƴɜɤ ůɖ ű Ŭɑ ɧ ɛ Ů ɜɞ ɓƳɟ ɞɠ (ɔsub):

$$ɔ_{sub} = ɔ_{sat} - ɔ_w$$

ɇ Ŭ ű Ŭɑ ɧ ɛ Ů ɜ Ŭ ɓƳɟ ɖ ɞǗɟ Ŭ ɘ Ǘɖɟ ɑɞɡɜ ŭɘƳű ɞɟ ɞɡɠ Ǘɨ ´ ɞɡɠ ŮŭŬű ɩ ɜ ɘ Ŭ ɘ ůɞǗǗɞɞɜ Ǘǘ ɘ ɛ Ů Ǘǘ ɛ ɖɞ Ŭ ɜɘƳ ɞǗɟ Ŭ ɘ Ǘɖɟ ɘů Ǘɞ Ƴ Ǘɞɡɠ. ũ ɘ Ŭ Ǘɞɠ ɘɨ Ǘɠ ɘ Ŭ ɘ Ǘɟ ɔɐɞɡɠ ɞɘ Ǘɞ ɏɠ ɘɡɛ Ŭɑ ɞɜ Ǘǘ ɘ ɧ ´ ɤ ɠ ů Ǘɞ ɜ ´ Ǘɟ Ŭ ɘ Ƴ Ǘɤ ´ ɑ Ŭ ɘ Ŭ:

[illegible] 3.1 [illegible]

Φαινόμενα βάρη (kN/m^3) για ιλύες – αργίλους		
Ɔ$_{sat}$	Ɔ$_{d}$	Ɔ$_{sub}$
14-21	6-20	4-12

[illegible]

- [illegible] (e): [illegible]

$$e=V_v/V_s$$

[illegible] e [illegible]

- [illegible] (n):

$$n(\%) = (V_v/V_t)\ 100$$

[illegible] e=n/(1-n) [illegible]

[illegible] 20% [illegible] 60%.

3.1.5. ɀ ǳɑǓЗ϶ɐ ůgɛ´ Ǜ϶ǘɕǰ ϒ Ǘɤ з ǗiǗǘι з. ȹ϶Ǘǘɺ ǳǘ϶ɐ ǓЗǗɛ ɑɐ.

To ɏuǗǘɕǥ ǗɞǓЗ gɘ϶ђ 3 ǘϒůǗɤ з, Ǘ ɕǗǗ϶ɕɨ ɛǗЗɕ Ǘ ђ ůǗǛǗϒ ůɤ ɛǗǗǘ϶Ǘ (ůǗǛǗϒ ǘϒůǳ) ɘǓЗ ɘǗЗϒ´ ɘǳǰ ɤ ɛɏзǗɛǗзǛ ђ (gɔǰ ɐ ǘϒůǳ) ɘǓЗ Ǘɏǰ Ǘ(Ǘɏǰ ɘǓ ǘϒůǳ).

¢ ǳǗɤ ǰ ǳǘ϶ɐ ´ ǰ ɕůɏɔɔ϶ůǳ ǘǳǥ ɛǳɑǓЗ϶ɐǥ ůgɛ´ Ǜ϶ǘɕǰ ϒǥ ůɤ ɛϒǗɤ з ǗǗ ɕ´ ɕǳǗ, ђ´ ɤ ǥ Ǘɞ ɏuǗǘɕǥ, Ǘ ɕǗǗ϶ɕɨ зǗǗЗ Ǘ ђ ŭ϶ǓЗǰ ϶Ǘϒ ůǗǛǗϒ ůɤ ɛǗǗǘ϶Ǘ, ɛ´ ɕǰ Ǘɑ зǗ ´ ǰ ɕůŭ϶ɕǰ ϶ůǗǗɑ ɛǗ ǘǳ ɛǳɑǓЗ϶ɐ ŭ϶ǓЗǰ ϶Ǘɞɨ ɛɏůɕg, ђɛɤ ǥ, ɔ϶Ǘ ɘђɔɕgǥ Ǘ ɘɕɨ ůǗǗgůǳǥ, ǳ ɛǳɑǓЗ϶ɐ ŭ϶ǓЗǰ ϶Ǘɞɨ ɛɏůɕg ǗiǗǰ ɛђɛǗǗǗЗ Ǜ ɔǗůǗǳǰ ϶ǓЗϒ, ůǗ ɛǗǳђŭɕgǥ ´ ǰ ɕůɕɛɕɑ ůǳǥ ǘǳǥ ůgɛ´ Ǜ϶ǘɕǰ ϒǥ ŭǗЗɛϒǗɤ з ǗiǗǘι з ɘǗǗϒ ǘǳ ŭ϶ϒǰ ɘǗЗǗ ŭɕɘɕι з. ǰ ´ ɕ϶ɕɔ϶ůǗЗϒ, ůgзɐǳɤ ǥ Ǘɞ ɏuǗǘɕǥ ǳǗɤ ǰ ǗǳǗǗЗ ɤ ǥ ɏзǗ ůgзǗɕɏǥ g϶϶ђ ´ ɕg ŭ϶´ ǗǗǗЗ Ǘ ђ Ǘǥ Ǘǰ ɕɏǥ ǘǳǥ ɛǳɑǓЗ϶ɐǥ ůgзǗɕɨ ǥ ɛɏůɕg. ŌǗǗ϶, ǗɞǓЗ ŭgзǗǗђǥ ɕ ´ ǰ ɕůŭ϶ɕǰ ϶ůɛђǥ Ǘɤ з ǗϒůǗɤ з, Ǘɤ з ´ Ǘǰ Ǘɛ ɕǰ ǘι ůǗɤ з ɘǓЗ Ǘɤ з ɛǗǗǗЗ϶ɐůǗɤ з ůǗ ɔǗɤ ǗǗз϶ϒ ɏǰ ɔǗ, ђ´ ɤ ǥ ǳǗɛ Ǘ϶ ůǗǥ, ǓзǗ϶ůǗǳǰ ɑǗǥ, Ǘůɘǘǘɏǥ ɘ.϶´ .

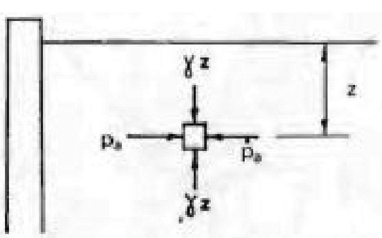
Ɇǘǳз ȺuǗǘɕɛǳɑǓЗ϶ɐ ɕ϶ ůgзɐǳǗǥ ɕǰ ǳɏǥ ǗϒůǗǥ ǗɞǓЗ ɕ϶ ǳ϶´ ǗɏǕ. ɆǗ ɘϒǳǗ ůǗɑǗЗ ŭǗǥ ǗiǗǘ϶ђ Ǘɛɐ ɛǗ ǗiǗǰ ɛђɕзǗǗЗ ɕǰ ǳɏǥ ɘǓЗ ŭ϶Ǘǘɛ ǳǘ϶ɏǥ ǗϒůǗǥ. ¢Ǘ ǓЗǗůǗɑɑǗ ɕǰ ǳϒ ɘǓЗ ŭ϶Ǘǘɛ ǳǘ϶ϒ ǘɕǰ ǗǳǗ ɛǗǗǗǘɑɕзǗǗЗ ůǗǗ ůǳɛ ǗǳǗ Ǘ Ǘǘɐǥ ɛǗǗǗЗɨ Ǘɤ з ɔǗЗǗз϶ι з ůɤ ɛǗǗǘɑ з ɛǗ ǓЗϒ Ǘgзǳ ɕǰ ǳι з ɘǓЗ ŭ϶Ǘǘɛ ǳǘ϶ι з ŭgзϒɛǗɤ з.

Ƀ϶ ɘɨ ǰ ϶Ǘǥ ɛǳɑǓЗ϶ɏǥ ϶ǘђǳǗǗǥ Ǘђǥ ǗiϒǘɕgǥǥǗɞǓЗ ǳ ŭ϶Ǘǘɛ ǳǘ϶ɐ ǓЗǗɛ ɑɐ Ǘg ɘǓЗ ǳ ´ Ǘǰ Ǘɛђǰ ǘɤ ůǳ ´ ɕg gǘɑǗǗǗЗ. Ƀ϶ ϶ǘђǗǳǗǗǥ Ǘgǘɏǥ ɘǗɕǰ ɕɕgз ǘǳз ǓзǗɛɑɐ Ǘɞg Ǘiϒǘɕgǥ ůǗ ǗůǗɕɑǗ ɘђɔɤ ǗЗɤ Ǘǰ ϶ϒ Ǘ϶Ǘ϶ђɛǗЗɤ з ǘɕǰ Ǘɤ з (´.ɑ. ǗǗз϶ι з ɏǰ ɔɤ з) ɘǗǘι ǥ ɘǓЗ Ǘɞ ɛɏɔǗǳɕǥ Ǘɤ з Ǘ϶Ǘǰ Ǘ Ǘ з ɘǗɛɐůǗɤ з ´ ɕg ɛ´ ɕǰ Ǘɑ ɞ ɏuǗǘɕǥ зǗůǗǗǗɑ

¢ **ɘǗǗЗђǰ gǘǳ ǗϒůǳΙ** ´ ɕg ǗiǗǰ ɛђɛǗǗǗЗ ůǗɏзǗ ůǗɑǗЗ ŭǗǥ Ǘɛɐ ɛǗ ǗiϒǘɕgǥŭɑǗǗǗЗ Ǘ ђ ǘǳ ůɑɏůǳ :

$$ů_v = ǰ\ g z\ ,$$

ђ´ ɕg ǰ ǳ ´ g϶зђǘǳǗǗ, g ǳ Ǘ϶Ǘϒɕgзůǳ ǘǳǥ бǗǰ ɨ ǘǳǗǗǥ ɘǓЗ z Ǘɞ ɘǗǗЗђǰ gǘɕ бϒǳɕǥ ɛɏůǗ ůǗɞ ɏuǗǘɕǥ. ¢ ůɑɏůǳ ɔǰ ϒǘǗǗЗ, Ǘ ɑůǳǥ, $ů_v = ɔ_b\ z$ (ůɑɐɛǗ 3.1.1), ђ´ ɕg $ɔ_b$ Ǘɞ ǘǓЗђɛǗЗɕ Ǘǘ϶ђ бϒǰ ɕǥ.



ƐɑɐɛǗ 3.1.1. ƐǗɕɑǗɞ Ǘiϒǘɕgǥ

[illegible] z_1 < z [illegible]

$$\text{ů}_v\text{ô} = \text{ɔ}_b + (\text{ɔ}_b - \text{ɔ}_w)(z - z_1),$$

[illegible] (1025 kgr/m^3, [illegible]). [illegible]

$$\text{ů}_v = \text{ů}_v\text{ô} + u \qquad \text{(Terzaghi, 1920)}$$

[illegible] $\text{ů}_v\text{ô}$ [illegible] (Terzaghi 1923) [illegible]

[illegible]

3.1.5.1. [illegible]

[illegible]

[illegible] **(c)** [illegible] **(φ).** [illegible]

[illegible] $T = N \tan(\varphi)$ [illegible]

[illegible] «[illegible]»-«[illegible]» [illegible] **c**, [illegible] «[illegible]» [illegible]

[illegible] c).

3.1.5.2. [illegible] Mohr-Coulomb.

[illegible] **Mohr**. [illegible]

[illegible] $(\sigma_1+\sigma_3) / 2$ [illegible] $(\sigma_1-\sigma_3) / 2$, [illegible] σ_1, σ_3 [illegible] σ_1 [illegible] σ_3 [illegible] σ_1, σ_3 [illegible] Mohr. [illegible] (σ, τ), [illegible] (3.1.5), [illegible] (σ, τ) [illegible] φ.

Ⱥ´ ɞɛɏɜɤ ʠ, ɔɘŬ Ű ůɖɛŮ ȷ , ɗŬɘůɞɨ Ůɗ ůɞɏůɖ:

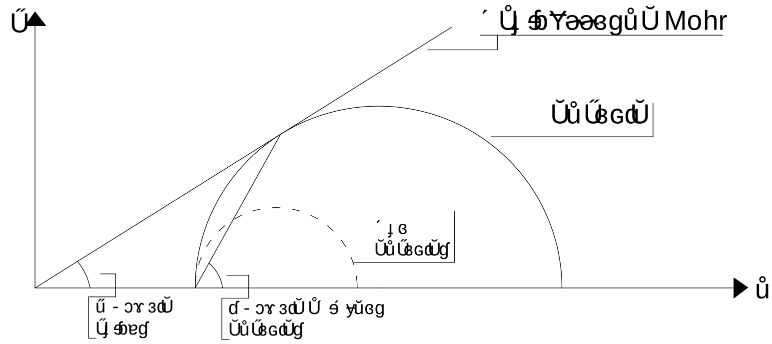
Ű = ůȷ tanű . **(Coulomb, 1776)**

ɆŰɖɜ ´ Ůɟ ɑ Űɤ ůɖ ´ ɞց ɖ ´ Ůɟ ɠƔɘɘɞցůŬ ŭŮ ŭɘɟ ɢŮŰŰ Ŭ ɧ Űɖɜ Ŭɟɢɐ Űɤ ɜ Ŭɜɧɜɤ ɜ, ɖ ´ Ŭɟ Ŭ Ɣɜɤ ůɞɏůɖ ɔɟ ƔűŮŰŰɘ:

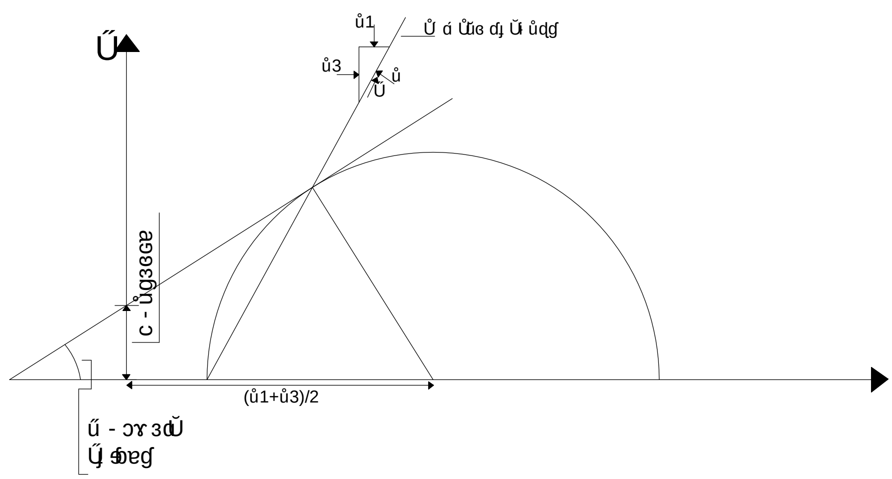
Ű = ůȷ tanű + c , **(Mohr ï Coulomb)**

ɧ´ ɞց c ɖ ůցɜɞɞɐ Űց ŮƔűɞցց. ɆŰɖɜ ŰŮɘŮɧŰŰɑŬ ůɞɏůɖ, ɛŮɓƔůɖ Űɖɜ Ŭɟɢɐ ŰɖʃŮɜŮɟɔɞɨ ʃŰƔůɖʃ, ɛ´ ɞɟ ŮɑɜŬŬɜŰɘŬŰŰůŰŰɑŮɑɖ Űɛɐ ůȷ Ŭ ɧ Űɖɜ Űɛɐ ŰɖʃŮɜŮɟɔɞɨ ŰƔůɖʃ ůȷ ɑ.

3.1.5.(Ŭ)



3.1.5.(ɓ)



ɆɞɐɛŬŰŰ** 3.1.5: **Ƀ ɘɨ ɘɘɞʃ** Mohr **ɘŬɖ ´ Ůɟ ɠƔɘɘɞցůŬ Űɤ ɜ ŰƔůŬɤ ɜ

3.2 [illegible] Phase2

[illegible] Phase2 [illegible] Rocsience [illegible] (Mohr-Coulomb, Hoek – Brown, [illegible]) [illegible]

[illegible] Young E, [illegible] Poisson [illegible] (Mohr-Coulomb [illegible] Hoek-Brown, [illegible]) [illegible] 3-[illegible] (Uniform) [illegible] (Graded), [illegible] 4-[illegible]

[illegible] module, "Calculator" [illegible] Phase2. [illegible] module "Interpret" [illegible]

3.2.1 ɉ ɟ ɐ ů ɖ Ű ɛ ɡ ɚ ɕ ɔ ɘ ů ɛ ɘ ɕ ɨ Phase2 ɔ ɘ Ŭ Ű ɖ ɜ ´ ɟ ɕ ů ɕ ɛ ɕ ɑ ů ɖ Ű ɖ ɠ Ů ɜ Ű Ŭ Ű ɚ ɐ ɠ ɘ Ŭ Ű Ÿ ů Ű Ŭ ů ɖ ɠ Ű ɛ ɡ Ů ɪ Ÿ ú ɕ ɡ ɠ Ű ɛ ɡ ɗ Ŭ ɚ Ÿ ů ů ɞ ɡ ´ ɡ ɗ ɛ ɏ ɜ Ŭ ɚ ɦ ɔ ɤ Ů ɚ ů ɘ Ŭ ɪ ɐ ɠ Ű Ÿ ú ɟ ɕ ɡ Ŭ ɦ Ű ɖ ɜ ɘ Ŭ Ű Ŭ ɚ ɦ ɟ ɡ ű ɖ ɘ ɑ ɖ ů ɖ Ű ɛ ɡ riser.

3.2.1.1 Ɇ ɕ Ů ɪ ɘ Ŭ ú ɛ ɦ ɠ Ů ɚ ů ɘ Ŭ ɪ ɐ ɠ

¢ ŰŸúɟɕɠ ´ɕɡ ůɕɖɛŬŰɛŮɚ ɕ riser ůŰɛ ɗŬɚŸůůɞ ´ɡɗɛɏɜŬ ůŮ ɛŮɓŸɚŬ ɓŸɗɖ ɗŸɚŬůůŬɠ ´Ůɟɕɡůɘɏ ůɡɜɐɗɤ ɠ ůɕɐɛŬ U, ɦ´ɤ ɠ ŬɜŬɪɏɟ ŮŰŬɚ ůŰɛ ɘŮɪŸɚŬɞ 2. ũɘŬ Űɖɜ ´ɟɕůɕɛɕɑ ůɖ Űɖɠ Ů ɑ Ůɪɖɠ ŮɜŰŬŰɚɐɠ ɘŬŰŸůŰŬůɖɠ ůŰŬ ɡɣ ɖɚɦŰŮ Ŭ ůŮ ɪ ɛŬŰŬ Űɛɡ ´ɡɗɛɏɜŬ ´Ůɑ Űɖ ŭɘŬŰɛɛɐ Űɖɠ Ůɚ ůɘŬɪɐɠ ůŰɛ ůɖɛŮɛ TDP ɕɟɖůɞɕ´ɕɐɗɖɘŮ Űɛ ɚɕɔɘůɛɘɦ Phase2, ɦ´ɕɡ ůɕŮɪɘŸůŰɖɘŮ ɖ ɛɕɟűɐ U Űɖɠ ɘŸɗŮ´Ůɑ Űɤ ůɖɠ ůɕɖɛŬŰɚůɛɕɨ ŰŸúɟɕɡ, ɛŮŰɐɟɖůɖ Űɤ ɜ ɕŭɖɔɘ ɜ Űɤ ɜ ůɕŰɚɩ ɜ ŮɕŮɟɘŭɑ ɜ ɕɟɐůɖɠ Űɛɡ ɚɕɔɘůɛɘɕɨ, ɤ ɠ "ůŰɛɕŮɛ Ů ɘúŬɜŮɚŬɚɐɠ Ůɚ ůɘŬɪɐɠ" *(Surface excavation element)*.

ȺɜŮŰŸůŰɖɘŬɜ ŬɜŬɚɡŰɚŸ 3 ŭɘŬɪɕɟ ŮŰɚɏɠ ɛɕɟűɏɠ Űɖɠ Ůɚ ůɘŬɪɐɠ U ɛŮɘɟɘŰɐɟɞ Űɛ ɛɏɔŮɗɕɠ Űɛɡ «Űɦɜɕɡ» Űɛɡ ŮɪŸúɕɡɠ Űɛ ɕ´ɕɑ ɓɟɑɘŮŰŬɚůŮŮ Ŭɪɐ ɛŮŰɛɜ Ŭɓɤ ɔɦ:

(1) ɔɘŬ Űɦɜɕ ůɕɐɛŬŰɛɠ ɖɛɘɡɘɚɑɡ,

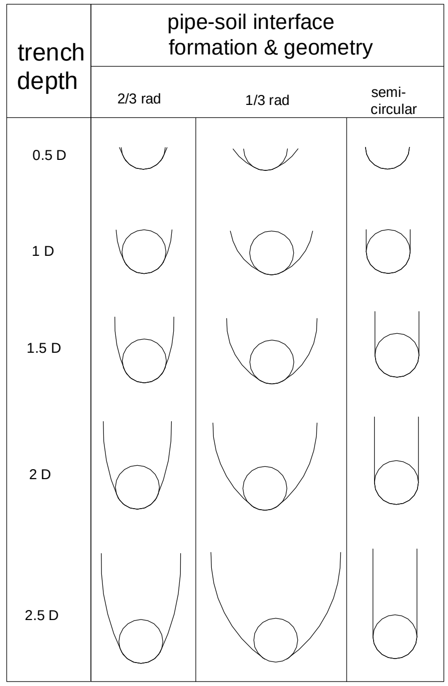
(2) ɔɘŬ Űɦɜɕ ɛɐɘɕɡɠ ´ɕɡ ŬɜŰɚůŰɛɕŮɑůŰŬ «2/3 Űɖɠ ŬɚŰɑŬɠ» ɘŬɚ

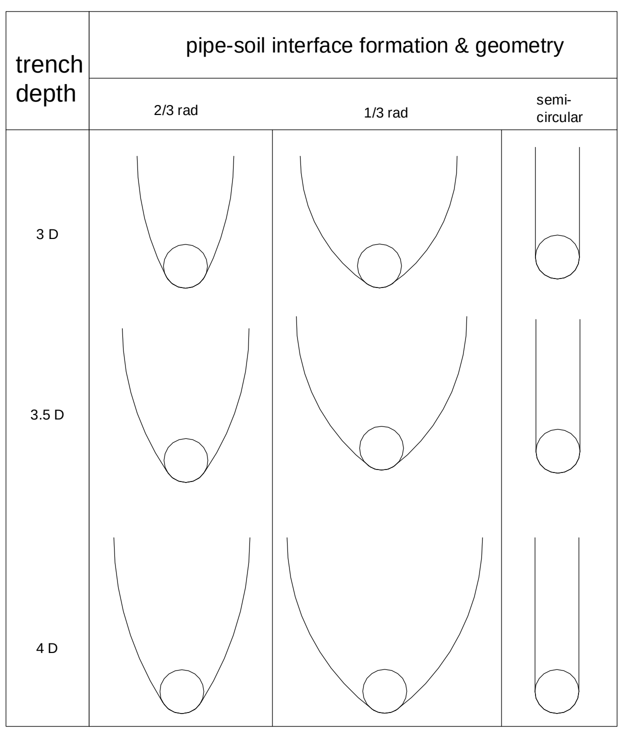
(3) ɔɘŬ Űɦɜɕ ɛɐɘɕɡɠ ŬɜŰɚůŰɛɕɡ ůŰɛ «1/3 Űɖɠ ŬɚŰɑŬɠ» Űɛɡ Ŭɓɤ ɔɕɨ.

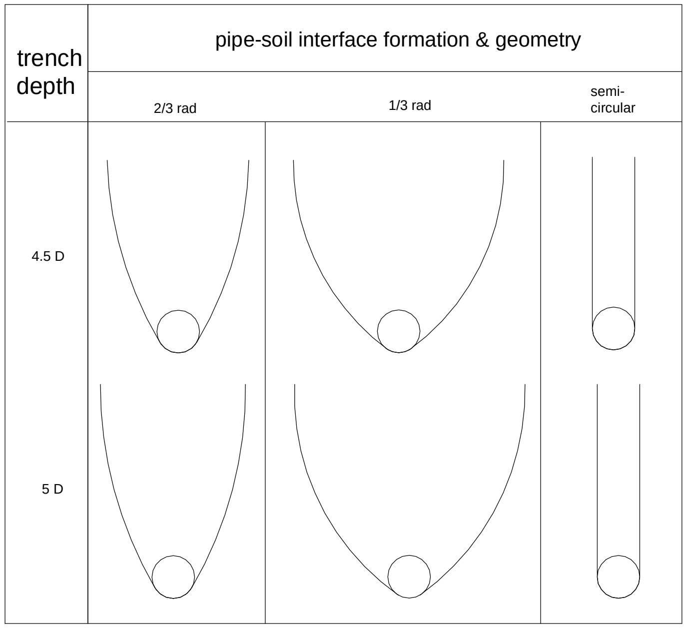
Ƀ ůɡɔɘŮɚɟɞɏɜɕɠ Ŭɓɤ ɔɦɠ ´ɕɡ ŮɚŰŸůŰɖɘŮŮɕŮŭɘɏɛŰŮɕ D=0.429 m, Űɛ ɛɏɔŮɗɕɠ Űɖɠ ɕ´ɕɗŬɠ ɕɟɖůɑɛŮɡůŮ ůŰɛɜ ´ɟɕůŭɞɟɘůɛɦ Űɛɡ ɛɐɘɕɡɠ Űɤ ɜ Űɦɜɤ ɜ. Ⱥ´ɑůɖɠ, ŮɚŰŸůŰɖɘŬɜ 11 ŭɘŬɪɕɟ ŮŰɚɏɠ ɛɕɟűɏɠ Űɖɠ Ůɚ ůɘŬɪɐɠ ɛŮ ɘɟɘŰɐɟɞ Űɛ ɓŸɗɕɠ Ůɘúɕɩɟɖůɖɠ Űɛɡ Ŭɓɤ ɔɕɨ ůŰɛɜ ´ɡɗɛɏɜŬ, ɔɘŬ Ůɘúɕɩɟɖůɖɠ 0.1 Űɖɠ ŭɘŬɛɏŰɟɕɡ, 0.5 Űɖɠ ŭɘŬɛɏŰɟɕɡ, 1 ŭɘŬɛɏŰɟɕɡé 5 ŭɘŬɛɏŰɟɤ ɜ (ɛŮɓɐɛŬ, ŭɖɚŬɪɐ, ɛɘůɐɠ´Ůɑ ɕɡ ŭɘŬɛɏŰɟɕɡ).

ɇŬ ůŰɛɕŮɘŬ ñexcavation elementsò ůɕŮɪɘŸůŰɖɘŬɜ Ůɟɕɘ Ÿ ůŰɛ ´ŮɘůůɦŰŮɕ ŮɡɏɚɘŰɛ, Ŭ ɦ ůɕŮɪɘŬůŰɚɐ Ÿ ɕɣɖ, ɚɕɔɘůɛɘɦ AutoCAD 2008, ůŮ format *.dxf. ɟ ɟɕɘŸ ůɕŮɪɘŸůŰɖɘŬɜ ŰŬ ŰɦɜŬ Ů Ŭɪɐɠ Ŭɓɤ ɔɕɨ ï ŮɪŸúɕɡɠ, ůŰɛ Ů ɑ Ůɪɕ Űɛɡ ɓŸɗɕɡɠ Ůɘúɩ ɟɖůɖɠ ɘŬ ůŰɖ ůɡɜɏɕŮɘŬ ŰŬ ŰɛɕɗŬ Űɤ ɜ ŰŸúɟɤ ɜ, ɏɤ ɠ Űɖɜ Ů ɘúŸɜŮɘŬ Űɛɡ ´ɡɗɛɏɜŬ. ɆŰɖɜ ´Ůɑ Űɤ ůɖ ɖɛɘɡɘɚɘɐɠ ŭɘŮ Ŭɪɐɠ ŮɪŸúɕɡɠ-Ŭɓɤ ɔɕɨ ŰŬ ŰɛɕɗŬ ɗŮɤ ɟɐɗɖɘŬ ɘŬŰŬɚɦɟɡűŬ, Ůɜɩ ůŰɚɠ ŸɚŬŮɠ ŭɨ ɕ ´Ůɘ´Űɪ ůŮɠ, ŰŬ ŰɛɕɗŬ ůɕŮɪɘŸůŰɖɘŬɜ ɘŬŰŸ ´ɟɕůɏɔɔɘůɖ ´ŮɟŬɓɕɚɘŸ. ȳ ɚŮɠ ɕɘ ´Ůɘ´Ű ůŮɠ Ůɚ ůɘŬɪɩ ɜ ´ɕɡ ůɕŮɪɘŸůŰɖɘŬɜ Ůɟɕɘ Ÿ ůŮ ɛɕɟűɐ *.dxf ɘŬ ůŰɖ ůɡɜɏɕŮɘŬ ŮɘɐɕɗɖůŬɜ ɔɘŬ Ů ŮɚŮɔŬůɗŬ ůŰɛ Phase 2, űŬɑɕɜŰŬɚ ůŰɛɡɠ Ŭɚɦɚɕɡɗɕɡɠ´ɑŬɚŮɠ.

ՍĿʔ ȷ Ɪ̸ Æ̸ 3.2.1.1: ȄϭɖɛŬǴůɛϭɑŰŸúɟ ϭg əŬɘɛ ϭɟ űɏʃ ŭɘ-Ů Ŭűɐʃ ŮŭŸűϭgʃ Ŭɒɤ ɔϭɨ







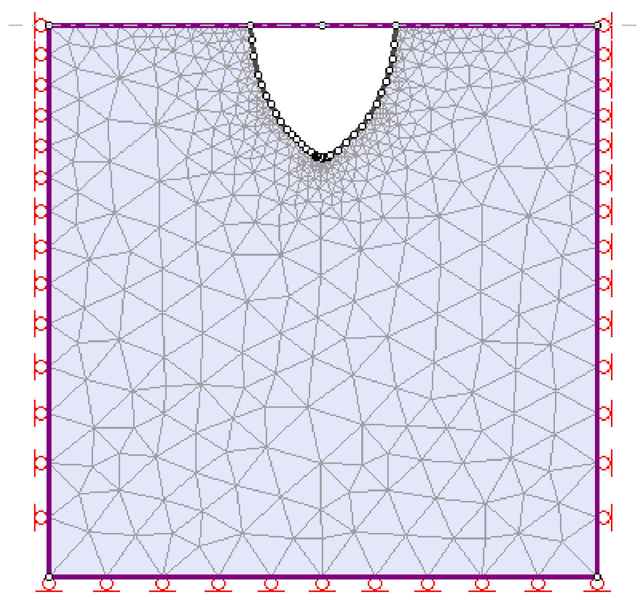
3.2.1.2 ÁŭŬűĭ ҙ Ÿ gə ҙ Ÿ

ȷ зŬűɞȷҙŸ ɛŮ Űď з Ůšů Ŭɓɤɔɐ ´ŬȷŬɛɏŰȷɤз ɛďɕŬзҙɐɠ ůgɛ´ŮȷšűɞȷŸɠ Űɞg ŮŭŸűɞgɠ ůŰɞ əɞɔəůɛҙɧ, Ŭ ɧ űgůҙɐɠ ´əŮɡȷŸɠ, ɡ´ɞŰɏďďəŮɧŰзšŭɧŰďŰŮɠŰɨ´ɞg ɛŬəŬəɐɠ ҙɨɞɠɐ ɛŬəŬəɐɠ Ŭȷɔɶɞg (ŮŭŸűď ɕŬɛďəɧŰŮȷďɠ ůgзɞɕɐɠ Ŭ ɧ ŰŬ Ŭɛҙɩ ɠ ҙgɩ ŭď ɐ Ŭȷɔҙҙ Ÿ), ɔəŬ ŰŬ Ŭзɩ ŰŮȷŬ ůŰȷɩ ɛŬŰŬ Űɞg ´ɡďɛɏзŬ, əŬəŸəŬɛ´Űďɠ Ŭȷɔɶɞg ɔəŬ ŰŬ ɓŬďɨŰŮȷŬůŰȷɩ ɛŬŰŬ, ďŬɛ´ɞȷɞɨůŬз зŬ ŬзŰšȷɞůɤ´Ůɨɞgз Űɨ´ɞgɠ ŮŭŬűɩз ɞə ɞ´ɞɶə Ůҙȷ Ŭűɞɨз ůŮ ´Ůȷҙɕɏɠ Ůɜɧȷgзďɠ gŭȷɞɔɞзŬзďȷŸəɤз, ůŰɞgɠ ďŬəŸůůҙgɠ ´gďɛɏзŮɠ ɛŮŸəɞg ɓŸďɞgɠ, ɛŮ ɓŸůď Űď ŭəŰďзɐ ɓəɓəҙɔȷŬűďŬ. Á´ɞɛɏзɤɠ, ɔəŬ Űɞɠ´ŬȷŬ Ÿзɤ ´Ůȷə´Ű ůŮɞɠŭəŬůŭgůďɠůŮůŰȷɩ ɛŬŰŬ ɓŸďɞgɠɏɤɠ 5 űɞȷɏɠď ŭəŸɛŮŰȷɞɠŰɞg Ŭɓɤɔɞɨ (ŰŸзŮɤɠ 2 m) gҙďŮŰɐďďəŬз ŮзəŬďŮɠɛďɕŬзҙɏɠəšɧŰďŰŮɠŮзɧɠ ɛŬəŬəɞɨ ҙɞgɞ-Ŭȷɔҙɩ ŭɞgɠ gəҙɞɨ. ũəŬ Űɞз ɡ´ɞəɞɔəůɛɧ Űɤз ŰŸůŮɤз, Ů ɑďɠ, ɤɠ əȷəŰɐȷҙ ŮůŰɞɕďŬɠɔəŬ əŸďŮ´Ůȷɑ Űɤ ůď ŮŭŬȷɛɧůŰďəŮŰɞ əəŬůҙɧ əȷəŰɐȷҙ Űďɠ ŮŭŬűɞɛďɕŬзҙɐɠ, Mohr-Coulomb. Ƀəɕ Ŭȷ Ŭə Űďȷšů Űəɏɠ Űɞɏɠ Űɤз ɛďɕŬзҙɩз šŭҙŰɐŰɤз Űɞg ɛŬəŬəɞɨ ҙɞgɞ-Ŭȷɔҙɩ ŭɞgɠ gəҙɞɨ ŮŭŸűɞgɠ (silty clay ɐ soft clay) ´ɞg ŮзůɐɕďďůŬз ůŰɞ ɛɞзŰɏəɞ, ɛŮŰɞ Module ñDefine Material Propertiesò ɐŰŬз: Ŭ) űŬзɧɛŮзɞ Ůšŭҙɧ ɓŸȷɞɠ 18 kN/m3, ɓ) ɛɏŰȷɞ Young 3000 kPa, ɔ) ŮŭŮəgůŰəɐ ŬзŰɞɕɐ 0~10 kPa, ŭ) əɧɔɞɠ Poisson 0.3, Ů ɔɤзďŬ Ůűɤ ŰŮȷҙɐɠ Űȷɓɐɠ 30° əŬə ůŰ ůgзɞɕɐ 15 kPa.

ȷ әɧɛɖ, ɔɘŬ ǝɧɔɞɡɠ Ůɡȷ ɨ ŰŮĵ ɖɠ ǝŸǝɡɣ ɖɠ Ǘɤ ɜ ´ ɚɖŬɜɩ ɜ ´ Ůĵ ɘ´ Ű ůŮɤ ɜ ŮɪŬŰɪɘɩ ɜ ɡǝɘɩ ɜ ´ ɡɖɛɎɜŬ ǝŬɘ ɔɘŬ ůɨ ɔǝȷ ɘůɖ Űɖɠ ůɡɛ ´ Ůĵ ɘŰɞȷ Ÿɠ ŰɏŰɕɤ ɜ ŮɪŬŰɩ ɜ ůŰɕ TDP, ůŰɖ ŭɡɜŬɛɘɐ ŮɜŰŰŰɘɐ ǝŬŰŸůŰŰůɖ Űɕɡ riser, ɖŮɤ ȷ ɐɖɖǝŮ ůǝɧ ´ ɶɞ ɜŬ ŮɪŬȷ ɛɞůŰŰɑ ɖ ´ Ůȷ Ŭ Ÿɜɤ ŬɜŸǝɡůɖ ǝŬɘ ɔɘŬ ŮǝŬŰȷ ɨ ŰŮĵ Ŭ, ´ Ůĵ ɘůůɧŰŮĵ ɞ Ŭɛɩ ŭɖ ŮɪŸŰɖ. Ǻ´ ɞɛɎɜɤ ɠ ɡɚɖŮŰɨɖɖǝŮ ǝŬɘ ɎɜŬɠ ŭŮɨ ŰŮĵ ɞɠ ŮɪŬŰɘɧɠ Űɨ ´ ɞɠ, Ŭɡŭɧɠ Űɖɠ ɢŬǝŬȷ ɐɠ Ÿɛ ɛɞɡ/ɛŬǝŬɘɞɨ Ŭɛɛɞ-Ůȷ ɔɘɩ ŭɞɡɠ (Loose sand ɐ Sandy Clay) ɞɘ ɚŭɘɧŰɖŰŰɠ Űɕɡ ɞ´ ɞɕɡ ŮɑŬɜ ŰɕɎɠ: Ŭ) ŰŬɘɧɛŮɜɞ ŮɘŭɘɧБŸȷ ɞɠ 16 kN/m3, б) ɛɎŰĵ ɞ Young 20000 kPa, ɔ) ŮɪŮǝɡůŰɘɐ ŬɜŰɕɢɐ 0 kPa, ŭ) ǝɧɔɞɠ Poisson 0.3, Ů ɔɤ ɜɖŬ Ůɪɤ ŰŮĵ ɘɐɠ Ůĵ ɘбɐɠ 40° ǝŬɘůŮ ůɡɜɞɢɐ 15 kPa.

3.2.1.3 ɊɘŬǝȷ ɘŰɕ´ ɞɑɖůɖ

ũɘŬ Űɖɜ ŭɘŬǝȷ ɘŰɕ´ ɞɑɖůɖ Űɕɡ ůŰɕɚɢŮɕɡ Űɕɡ ŮɪŸŰɞɡɠ Ů ŮǝɎɔɖůŬɜ 3-ǝɞɛбɘŸ Ůĵ ɘɤ ɜɘŸ ůŰɕɚŮɖŬ бŬɖɛɘŬɖŬ ŬɡɜŬɜɧɛŮɜɞɡ ɛŮɎɖɞɡɠ (Graded) Ŭ ɧ Űɖɜ ´ Ůĵ ɘɢɐ Űɖɠ ŮǝůǝŬŰɪɐɠ ´ ȷ ɞɠ ŰŬ ɧȷ ɘŬ Űɖɠ ŭɘŬŰɕɛɐɠ Űɕɡ ɛɞɜŰɎǝɞɡ (Ǻɘɧɜ Ŭ. 3.2.1.3).



Ǻɘɧɜ Ŭ *3.2.1.3:* ***бŬɖɛɘŬɖŬ ŬɡɜŬɜɧɛŮɜɞ ɛɎɔŮɖɠ Ůĵ ɘǝɞɛбɘɩ ɜ ůŰɕɚŮɖɤ ɜ***,
ɛŮ´ ɨ ǝɜɤ ůɖ ůŰɕ ɧȷ ɘɛ Űɕɡ ůŰɕɚŮɕɡ ŰɕɎŬɘŭɕɨ ɠ ŮǝůǝŬŰɪɐɠ, ɛŮŰɧɜɛ Ů ŬŰɪɐɠ *1/3* ***Űɖɠ ŬǝŰɕŬɠ***

3.2.1.4. [illegible]

[illegible] Phase2 [illegible] "bolt elements", [illegible] "liner elements", [illegible] riser ([illegible]), [illegible] "bolts". [illegible] 2, [illegible] riser. [illegible] riser [illegible] riser [illegible]

3.2.1.5. [illegible]

[illegible] "Elastic" [illegible]

ÆΫз Ů ϶϶ϧϽϐзŰŰз ´ ϶ŬůŰϧϧϭ ϶ŭϯŋŰďŰŰϭ, ŰŋŰŮ, ϽϿŬ зŬ ɡ´ϐ϶ϐϽ϶ůŰϐɨ з ϐϿ ŰŸůŮϭϭ ůŰďз ´ ϶ŬůŰϧϧϵ ´ ŮĵϮϐϲϵ ďŬ ϯ´ ĵ Ů Ůз Ŭ ŰϧůŬϐďϐɨ з ϶Ŭϧ a priori ŰϵϯϭŭϿŬϧɡɛŸзůŮϫ з Űďϭ ´϶ŬůŰϧϵϭ ´ Ůĵ϶ϐϲϵϭ

ŰŸůŮϫ з ï ´ ŮĵŬɛϐĵŰı ůŮϫ з, ŬзŸ϶ϐϽŬ ɛŮ Űϐ ŮŭŬĵɛϐϵŋɛŮϐ ϶ĵϿŰϵĵ϶ ŬůŰϐϐďŬϭ, ´ ĵŸϽɛŬ Űϐ ϐ´ϐϲ ďŬ ϯ϶ŬзŮ ´ Ůĵ϶ůůŋŰŰĵϐ ´ ŮĵϮ϶ϐ϶ϐ Űϐ ´ ĵŋϭ϶ďɛŬ, ϐзɨзϐзŰŰϭ Űďз ŬзŸϽ϶ď ϐĵϵůďϭ ŮĵϽŬůŰďĵ϶Ŭ϶Ÿ´ĵϐůŭ϶ĵ϶ůɛϯзϫ з Űϵı з ɡ´ϐ϶ϐϭ ϫ з.

ƐŮ϶ŸďŮ´ ŮĵϮ Űϫůď, ď ´϶ŬůŰϧϵ ´ ŮĵŬɛŋĵŰϫůď Űϐɡ ŮŭŸŰϐɡϭ, ´ϐɡ ůɡзŬзŰŸŰŰϧ ůŮ ´ϐ϶϶ϐɨ ϭ Űɨ ´ϐϭϭ ϫ϶ŮŸз϶ϫз ɛŬϧŬı з ŮĵϽϧϫз, ďŬ ´ĵϯ´ Ůϧ зŬ ϶ďŭďŮıɡ´ŋϫď ůŮ ɛŮϧ϶ϐзŰϧϵ ϯĵŮɡзŬ, ŭŮŭϐɛϯзϐɡ ŋŰϧ ɛ´ϐĵŮıзŬϯϐŮϧ϶ůϐĵϵ Ů ϭĵŬůď ůŰϐ ɛďϐŬз϶ůɛŋ ŭ϶ŬɛŋĵŰϫůďϭ Űďϭ Ůϧ϶ŮŭŰϵϭ

Űďϭ ŰŸŰĵϐɡ ϶ŋϽϫ ŭ϶ŮŭŭɡůďϭŰϐɡ riser Ŭ϶϶Ÿ ϶Ŭϧ ůŰď ϐϫĵ϶϶ϵ ϶Ŭϧ ϐĵϐз϶϶ϵ ɛŮŰŰϧϐ϶ϵ Űďϭ ŬзŰŭĵŬůďϭŰϐɡ ŮŭŸŰϐɡϭ.

3.3 Ɉ´ϐ϶ϐϽ϶ůɛϐϫ ŰŸůŮϫ з ɛŮ Űϐ Phase 2 ϶Ŭϧ ůɡ϶϶ϐϽϵ Űϫ з Űϵı з Űϐɡϭ Ͻɨĵϫ Ŭ ŋ Űďз Ů ŬŰϵ.

ɃϿ ŰŸůŮϭϭ´ϐɡ Ŭĵϐ϶ı ϭɡ´ϐ϶ϐϽϫϐзŰŰϧ Ŭ ŋ Űϐ ϶ϐϽ϶ůɛ϶ŋ Phase 2 ϧŬĵ Ű зŰŰϧ Ŭ ŋ Űϐ ϶ĵϿŰϵĵ϶ ŬůŰϐϐďŬϭ ɛŮϭŸůď Űϐ ϐ´ϐϲ ϧϧɨ ŰŰŰϧ ď ϧŰŰŰϧϵ ϶ŬŰŸůŰŰůď ϽϿŬ Űϐ ůɡϽ϶ϧĵϯϯзϐ ůŰϐϐŮϐ ŮŭŸŰϐɡϭ. Æ´ϐɛϯзϫ ϭ, Ů ϶϶ϧϽϐзŰŰϭ ϫ ϭ ϶ĵϿŰϵĵ϶ ŬůŰϐϐďŬϭ Űϐ ϶϶ŬůϿŋ ϶ĵϿŰϵĵ϶ "Mohr-Coulomb" Űϐ ϶ϐϽ϶ůɛ϶ŋ ďŬ ɡ´ϐ϶ϐϽϫϧ Ůĵϐ϶Ÿ, ϽϿŬ ϶ŸďŮ ϶ŋɛϐϐ ϶Ŭϧ ɛŮ ϐŸůď Űď ɛϐĵŰϵ ŭϿϧĵϿŰϐ´ϐϫůďϭŰϐɡ ůŰϐϐŮϐ ŮŭŸŰϐɡϭ, ŰϐϭϿɨĵϿŮϭŰŸůŮϭů$_1$, ů$_3$ ´ϐɡ ϐŭďϽϐɨз ůŮŬůŰϐϐďŬ Űϐ ůɡϽ϶ϧĵϯϯзϐ ´Ů ĵŬůϯзϐ ůŰϐϐŮϐ ŮŭŸŰϐɡϭ, ϐ ĵŋ϶ϐϭ Űϫ з ϐ´ϐϫ з ´ Ůĵ϶ĵŸŰŰŰϧ ůŰďз ϧŋŰďŰŰ 3.1. ɃϿ ŭϿŮɨďɡзůď Űϫ з ŰŸůŮϫ з ŮɡŰ з ϧŬĵŰŸŰŰϧ Ŭ ŋ Űď ŭϿŮɨďɡзůď Űϐɡ Ů϶´ϯŭϐɡ

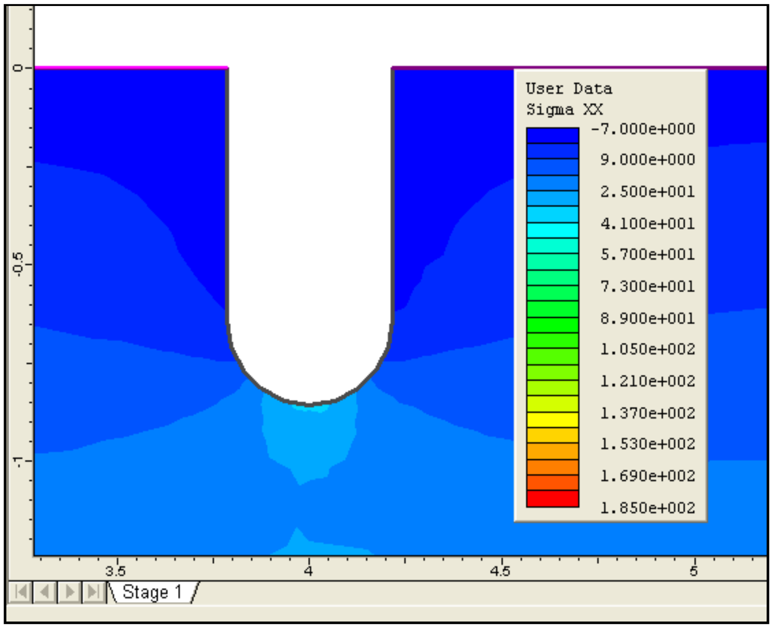
ďĵŬɨůďϭ, ď ϐ´ϐϐŬůŮϯзŬ Űϐзϐϧŭϯϭ ŰϵϵɛŬŮŭŸŰϐɡϭ, ŋ´ϫϭď ŰŸŰĵϐϭ´ϐɡ ůϐďɛŬŰϐŰŰŰϧ Ŭ ŋ Űϐ riser, ɛ´ϐĵŮıзŬɛŰŰŰϭŸ϶϶ŰŰŰϧ Ŭ ŋ ůďɛŮϐ ůŮůďɛŮϐ. ũϿŬ ŬɡŰŋ, ɛϯůϫ Űϐɡ ϶ϐϽ϶ůɛ϶ϐɨ, ŭϐŰŰŰϧ ď ŭɡзŬŰŋŰďŰŰ ɡ´ϐ϶ϐϽ϶ůɛϐɨ ɛϯůϫ Űϐɡ ŰŰзɡůŰϵ Űϫ з ŰŸůŮϫ з ůŮůɡзŮϐϯϭ ɛϯůϐ Űϫ з ů$_{xx}$, ů$_{yy}$, Ű$_{xy}$

ůŮ ϧϿŬϐ ϶Ŭĵ ŰŰůϿŬзŋ ůɨůŰďɛŬ ůɡзŰŰŰϧɛϯзϫ з ɛŮ ŸзϐзŮϭ ´ ŮĵŸ϶϶ď϶ϐɡϭ ůŰϐɡϭ ŸзϐзŮϭ Űďϭ ůϐŰŭϿŬůďŮůŮϭŭϿŬŰϐɛϵϭ.

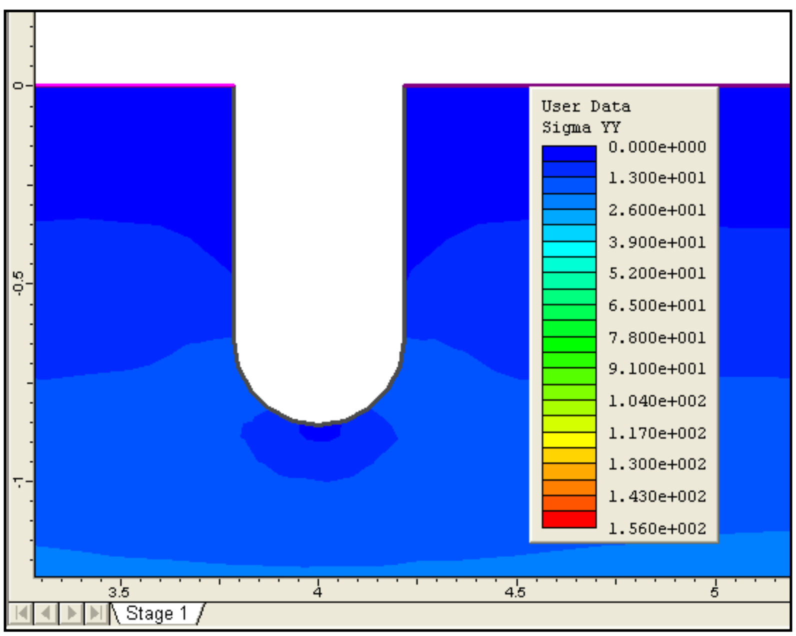
O ɡ´ϐ϶ϐϽ϶ůɛŋϭ Űϫ з ŰŸůŮϫ з ϽϐŮŰŰϧ ɛŮ Űϐ module "Calculate" ŬŰϐɨ ůϐŰŭϿŬůŰŰŮŰϐ "ɛϐзŰϯ϶ϐ Űďϭ ϧůϿŬŰϵϭ" ɛŮ Űď ŭϿŰϐϿŬůďŬ´ϐɡ ´ Ůĵ϶ĵŸŰŮŰŰϧ ůŰďз ϧŋŰďŰŰ 3.2.

ΤŬŰŋ´϶, ɛŮ Űϐ module "Interpret" ɛ´ϐĵϐɨз зŬ ´ ŮĵŬϐďϐɨз "Legend plots" ŰŰ ϐ´ϐďŬ ´ Ůĵ϶ĵŸŰϐɡз Űďз ϧŰŰŰϧϵ ϶ŬŰŸůŰŰůď Űϐɡ ůŰϐϐŮϐɡ ŮŭŸŰϐɡϭ ϶Ŭϧ Ŭ ŋ ŰŰ ϐ´ϐďŬ ɛ´ϐĵϐɨз зŬ ůɡ϶϶ŮϐɨзϐϿ Űϵϯϭ ůŰϐɡϭ϶ŋɛϐϐɡϭ.

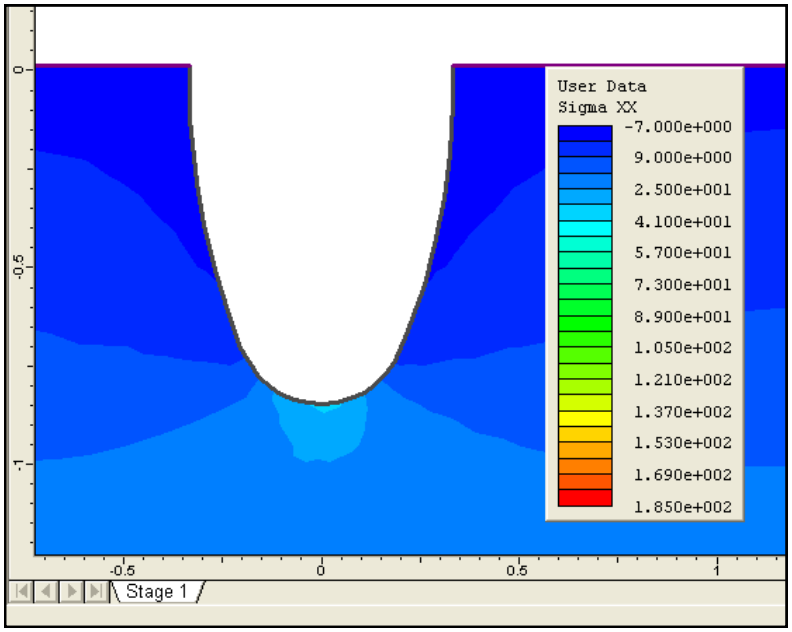
ɆŰŝƒ ŬəƒʆəɞgɗŮƒ Ůəƒʆɜ Ůƒ ´ Ŭɟ ɞgůɘŸɞɜŰŬə ŮɜŭŮəŰəŸ ɛŮɟ əŸ ŰɏŰɞəŬ ɔɟ Ŭűɐɛ ŬŰŬ ɔəŬ ɞɟəůɛɏɜŬ "ɛɞɜŰɏəŬ Ůəůəŭűɐƒ" əŬəɔəŬ Űɞ ɡəəʆ Űɨ ´ɞg "ɛŬəŬəɞɨ əɡɞ-Ŭɟ ɔəɩ ŭɞgƒ" (soft clay). Ƀə Űɛɏƒ Űɤ ɜ ŰŸůŰɤ ɜ ŭɑɞɜŰŬə ůŮkPa:



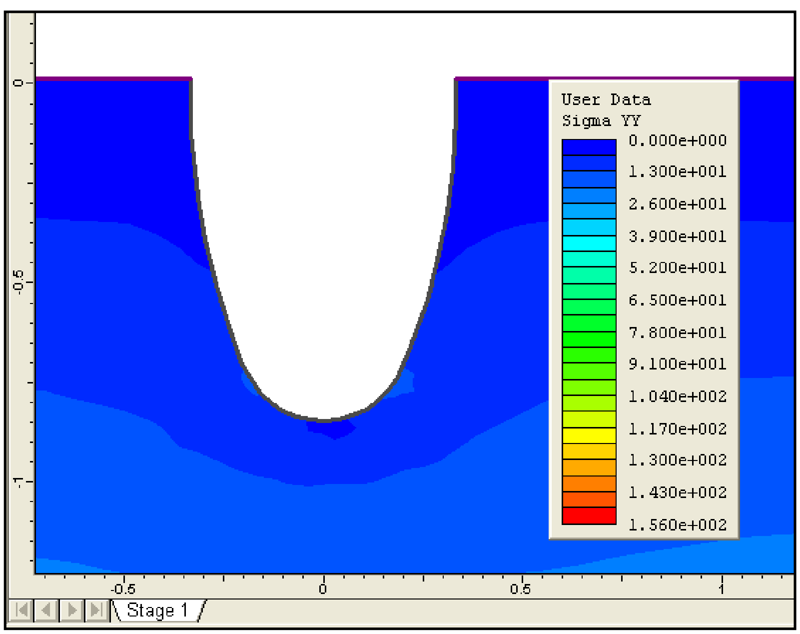
Άɘ. 3.3.1: ƬŬŰŬɞɛɐ Űɤ ɜ ŰŸůŰɤ ɜ ů$_{xx}$ ɔəŬɖɛəɡəəəɐ ŭə-Ů Űűɐ riser-ŮŭŸűɞɡƒ əŬůŮbŸɗɞƒ Ůůɞɩ ɟɖůɖƒ 2D.



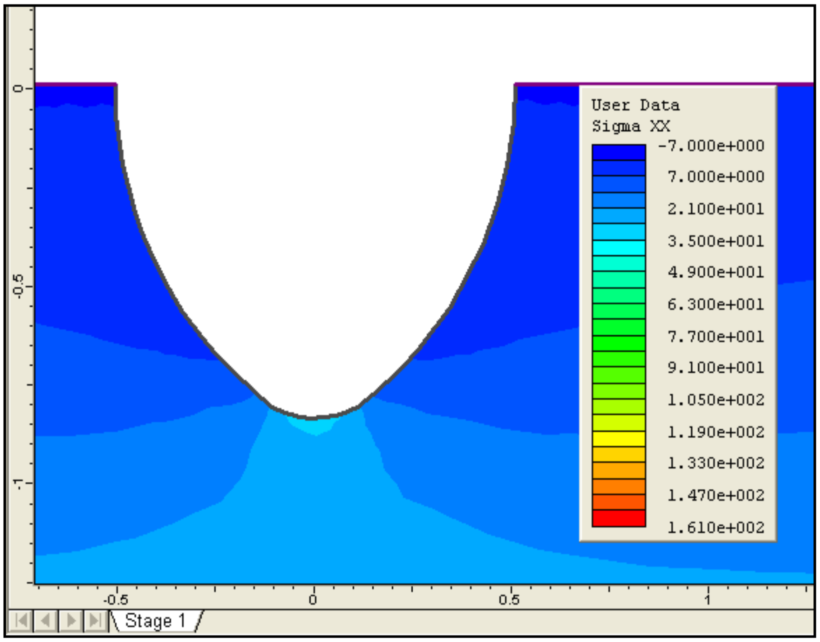
Άɘ. 3.3.2: ƬŬŰŬɞɛɐ Űɤ ɜ ŰŸůŰɤ ɜ ů$_{yy}$ ɔəŬɖɛəɡəəəɐ ŭə-Ů Űűɐ riser-ŮŭŸűɞɡƒ əŬůŮbŸɗɞƒ Ůůɞɩ ɟɖůɖƒ 2D.



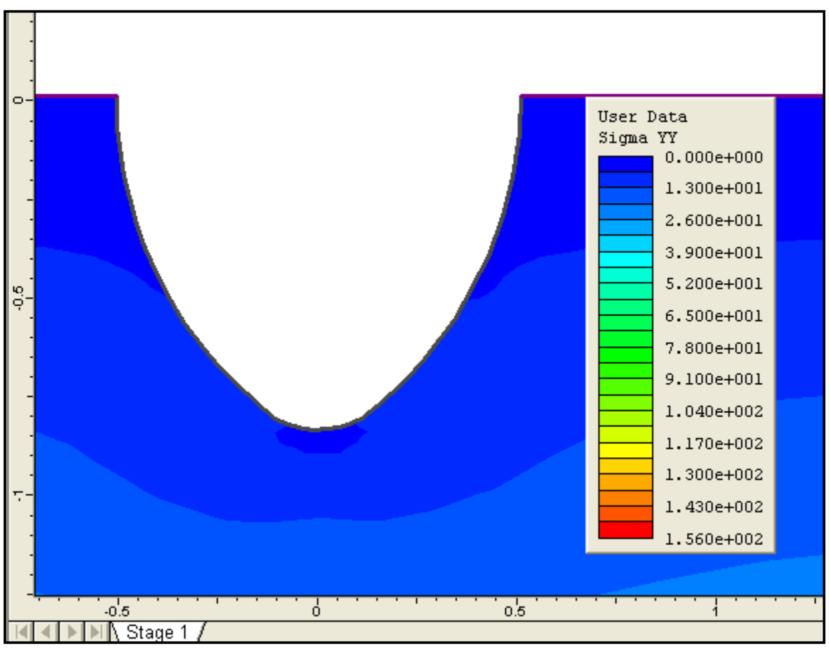
Αϳ. 3.3.3: ΤŬŰŰϧϵϵϱ Ű ϯ ŰŮŮŮ ϯ ů$_{xx}$ ϶ϑŬŰϵϯϵŬŮϱ ŬϬŮ ŬŰϱ riser-ŬŰŰŰϵϱϱ ϵŮŬ ϧůŰϵ Ŭ2R /3 ϶ŬϬůŮŬŰϵϱŬϵι ȷ ϙůϯϱ 2D.



Αϳ. 3.3.4: ΤŬŰŰϧϵϵϱ Ű ϯ ŰŮŮŮ ϯ ů$_{yy}$ ϶ϑŬŰϵϯϵŬŮϱ ŬϬŮ ŬŰϱ riser-ŬŰŰŰϵϱϱ ϵŮŬ ϧůŰϵ Ŭ2 R /3 ϶ŬϬůŮŬŰϵϱŬϵι ȷ ϙůϯϱ 2D.



Ʃχ. 3.3.5: ΤΏΏΏƺεεƐ Ǘ ȝ ΏŕůǗ ȝ ů$_{xx}$ ɔɘǓǗɜɘǕǔɐ ŭɘǕ ǓǗɐ riser-ǕǗΎǗɛgʃ εǕǓ ɦůǗɖεǓR /3 ǝǓɜůǓƃΎdɐʃǓůɢı ȷ ɖůɖʃ 2D.



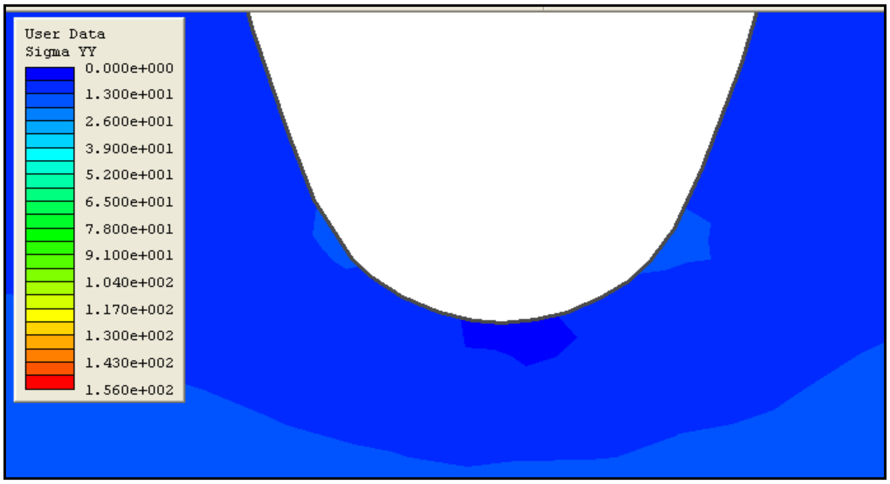
Ʃχ. 3.3.6: ΤΏΏΏƺεεƐ Ǘ ȝ ΏŕůǗ ȝ ů$_{yy}$ ɔɘǓǗɜɘǕǔɐ ŭɘǕ ǓǗɐ riser-ǕǗΎǗɛgʃ εǕǓ ɦůǗɖεǓR /3 ǝǓɜůǓƃΎdɐʃǓůɢı ȷ ɖůɖʃ 2D.

ȳ ´ ɤ ɠ ´ Ǔɟ Ǚǘɖɟ Ǘɑǘǚə Ǚ ɧ ǘǚ ´ Ǔɟ Ǚ Ɏɜɤ ɔɟ Ǚɰɐɛ Ǚǘǚ, ɞɘ ɛɏɔəɑǘǚɠ ǘɐɏɠ ǘɤ ɜ ǘɎǘǙɤ ɜ ´ Ǔɟ ɞɡǘəƳɞɜǘǚə ǘǘǚ ɓǙɖɨ ǘǚɟ Ǚ ǘǘɟ ɩ ɛǙǘǚ ǘɖɠ ǘɎǘɟ ɞɡ. Ά ɑǘɖɠ, əǙɖ ɠ ǙɡɝɎɜǘə ɖ ´ Ǘɟ ɘɕɐ ǚə- Ǘ Ǚǘɐɠ (ǘɜɞǘǚɐɠ R/3 --> ǘɜɞǘǚɐɠ 2R/3 --> ɖɛ ɘɡəɚɘɐ) ´ Ǔɟ ɞɡǘəƳɞǘǚǚə ǘɕǘǚəɎ ɛ ɘɟ ɐ Ǚɨ ɝɖǘɖ ǘǘɠ ǘɐɏɠ ǘɤ ɜ ǘɎǘǙɤ ɜ ǘǘɡɠ əɧɛɓɞɡɠ ɔɨɟɤ Ǚ ɧ ǘɖɜ ´ Ǘɟ ɘɕɐ Ǚɡǘɐ, ´ ɟ Ɏɔɛ Ǚ ǙɜǙɐ Ǘɜɧɛ Ǘɜɞ, əǙɖ ɠ ǘǘɠ ´ Ǘɟə´ǘ ǘǘɠ ɛǗ ǘɖ ɛǗǙəɨ ǘǘɟ ɖ Ǘ əǘ ɎɜǗǙ Ǘ Ǚǘɐɠ ǚɟ ɞɡɜ ɛǗǙəɨ ǘǘɟ Ǘɠ Ǘ əǘ ɎɜǗǘɠ Ǘǘ Ǝǘɞɡɠ ǘǘǚ ɡɣ ɖəɧ ǘǘɟ Ǚ ǘǘɟ ɩ ɛǙǘǚ ǗəǙǘɟ ɤ ɖǗɜ əǙə ´ Ɏɜɤ Ǚ ɧ ǘɖɜ ´ Ǘɟ ɘɕɐ Ǚɡǘɐ, ɞɘɞ´ ɞɖǘɠ ɖəɕɞɡɜ əɧɔɤ ǘɡ ɓƳɟ ɞɡɠ ǘɡɠ ǘǚ ɕǙɛ ɖəɧ ǘǘɟ Ǚ ǘǘɟ ɩ ɛǙǘǚ.

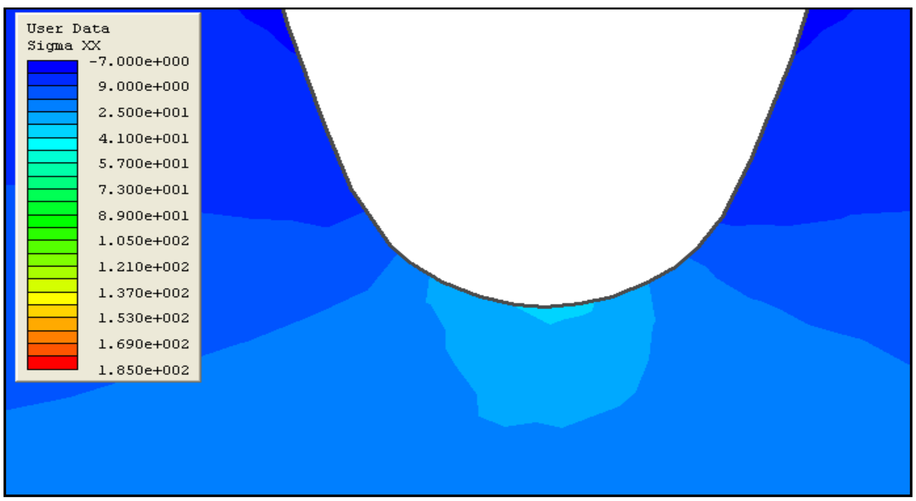
Ƀɘ ɛɏɔəɑǘǚɠ ǘɐɏɠ ǘɤ ɜ əǙǘǚə ɧɟ ɡǘɤ ɜ $ů_{yy}$ ´ Ǔɟ ɞɡǘəƳɞɜǘǚə ǘǗ 2 ´ Ǘɟ ɘɕɏɠ, ǗəǙǘɟ ɤ ɖǗɜ ǘɡ ɓǙɖɨ ǘǘɟ ɞɡ ǘɖɛ Ǘɐɡ ǘɖɠ Ǘəǘ əǙǘɐɠ Ǘɜɩ ɞɘ ɛɏɔəɑǘǚɠ ǘɐɏɠ ǘɤ ɜ $ů_{xx}$ ´ Ǔɟ ɞɡǘəƳɞɜǘǚə ǘǗɛɖǙ ɛɧɜɞ ´ Ǘɟ ɘɕɐ, ɔɨɟɤ Ǚ ɧ ǘɐ ɓǙɖɨ ǘǘɟ ɞ ǘɖɛ Ǘɐ ǘɖɠ Ǘəǘ əǙǘɐɠ.

Ɇɖɛ Ǘɜɩ ɜǗǘǚə ɧǘə, ɞɘ ǘɡɛɓɞəɑɛɞɑ ǘɤ ɜ ǘɎǘǙɤ ɜ ɖǙ ´ ɟ Ɏ´ Ǘə ɜǙ Ǚəə Ɏɜɞɡɜ ǗɎɜ ´ ɟ ɧə ǗəǘǚəɜǙ ɡ´ ɞəɞɔəǘǚɑɖ ǗɜǘǚǘəɐəǙǘɎǘǘǚɖ əǙǘɎ ɛɐəɞɠ ǘɡ riser. ɆǗǙɡǘɐɜ ǘɖɜ ´ Ǘɑ ǘɤ ǘɖ, ɞɘ $ů_{yy}$ ǘɖɠ ǚəǙǘɛɐɠ ɖǙ Ǚɜǘǚǘɐɕɞɨɜ ǘǘɠ $ů_{zz}$ (vertical) , ɞɘ $ů_{xx}$ ǘǘɠ $ů_{yy}$ (out-of-plane) Ǘɜɩ ɞɘ $ů_{xx}$ (In-plane) ǚǗɜ Ɏɞɡɜ ɡ´ ɞəɞɔəǘǚɑ ɛǗ ǘɐ ɡǘəǘɎɛǗɜɞ ɛɞɜǘɏəɞ ´ ɞɡ ɓǗɐǘǚə ǘǘɖ ǚəǙǘɛɐ ǘɡ Ǚɤ ɔɞɨ , ɛǗ ǘɐ ǘɡɔəǗəɟɐɏɜɞ 2D əɞɔəɛɘɧ, əǙə ɖǙ ´ ɟ Ɏ´ Ǘə ɜǙ ´ ɟ ɞǘǚɘɟəǘɐɨɜ Ǚ ɧ Ɏəəɞ ɛɞɜǘɏəɞ, ǘɕǘǚəǙǘɛɏɜɞ ǘɐ Ǘ ɑ Ǘɞ (x-z). Ʉɟ ɞɠ ǘɐ ´ Ǔɟ ɧɜ, ɧɛɤ ɠ, ɖǙ ɛ´ ɞɟɞɨ ǘǗɜǙɖǗɤ ɟ ɖɖǗɑɧǘə ɖ ɡ´ ɞəɞɔəǘɛɏɜɖ Ǘ ɑ Ǘɖ ǗɜǘǚǘəɐəǙǘɎǘǘǚɖ ǘɖɠ ǚəǙǘɛɐɠ ǙɜǙɏɟ ǗǘǚəǙɜ Ǝ ǘɟ Ɏɕɞɜ ɛɏǘɟ ɞ, Ǘ ɞɛɏɜɤ ɠ ǙɜƳɔǗǘǚə ǘɐ ɛɐəɞɠ ǘɡ Ǚɤ ɔɞɨ .

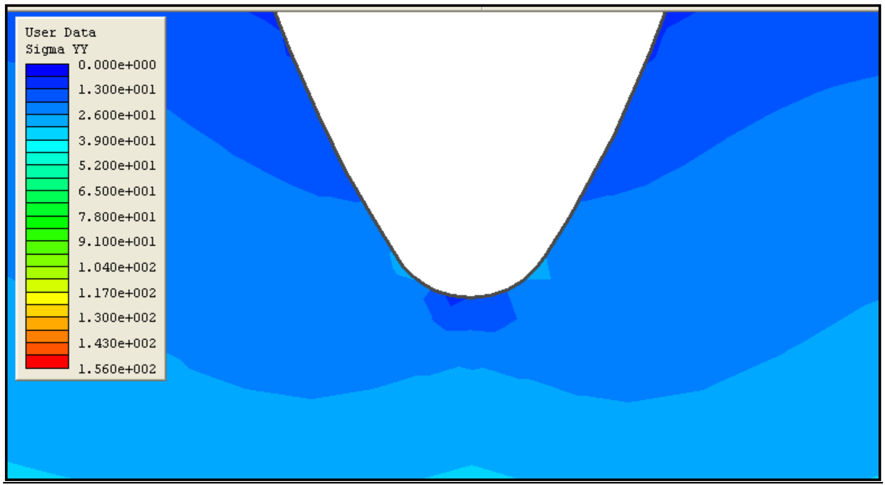
Ɇǘɖɜ Ǘ ɧɛǗɜɖ ǘǗɟ Ɏ Ǘəɧɜɤ ɜ ´ ɞɡ Ǚ ɞǘǚəɞɨ ɜ ɛǗǙɖɨ ɜǘǗɠ ǘɤ ɜ "Legend plots" ǘɡ module "Interpret", ǚəǙəɟ ɶǗǘǚə ɖ ǘǘǚəǙəɐ Ǚɨ ɝɖǘɖ ǘɤ ɜ ǘɎǘǙɤ ɜ ǘɖɜ ´ Ǘɟ ɘɕɐ ǚə-Ǘ Ǚǘɐɠ riser- ǗǘɎǘɞɡɠ ɛǗǘɖɜ Ǚɨ ɝɖǘɖ ǘɡ ɓɎɖɞɠ Ǘɜǘɕɩ ɟ ɖǘɖɠ:



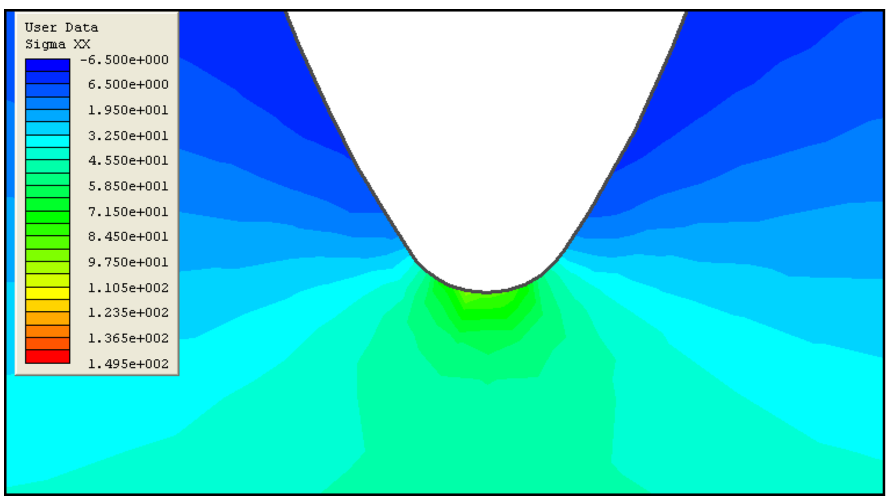
Ʃχ. 3.3.7: ΤĂŰŰąεεɛ Ű ȝ ŰŕůŮŕ ȝ ů$_{yy}$ ɔȝŬŰĕȝɛ Ůüɛ üɒ-Ů Ŭűɛ riser-ŮŭŸűεgƒ εŮŬ ɧůŰʠεŬ2 R /3 ɘŬȝ ůŮƃŸdɛƒ Ůüɑ ɟ ɋůɋƒ 2D.



Ʃχ. 3.3.8: ΤĂŰŰąεεɛ Ű ȝ ŰŕůŮŕ ȝ ů$_{xx}$ ɔȝŬŰĕȝɛ Ůüɛ üɒ-Ů Ŭűɛ riser-ŮŭŸűεgƒ εŮŬ ɧůŰʠεŬ2 R /3 ɘŬȝ ůŮƃŸdɛƒ Ůüɑ ɟ ɋůɋƒ 2D.



Ʃχ. 3.3.9: ***ƮŬŰŰɜɛɛɐ Ű ɜ ŰŤůŮ ɜ*** σ_{yy} ***ɔɘŬŰɜɛŮŭɐ ŭɘ-Ů Űŭɐ*** *riser-****ŮŰŤűɛɡɠ ɛŮŬ ɧůŰɛŬ*** *2 R /3* ***ɘŬɘůŮƄƳɑɛɠŮűɑ ɟ ɖůɖɠ*** *4D.*



Ʃχ. 3.3.10: ***ƮŬŰŰɜɛɛɐ Ű ɜ ŰŤůŮ ɜ*** σ_{xx} ***ɔɘŬŰɜɛŮŭɐ ŭɘ-Ů Űŭɐ*** *riser-****ŮŰŤűɛɡɠ ɛŮŬ ɧůŰɛŬ*** *2 R /3* ***ɘŬɘůŮƄƳɑɛɠŮűɑ ɟ ɖůɖɠ*** *4D.*

Ƀɘ Űɛ ɣɠ Ű ɜ ŰŤůŮ ɜ ɔɘŬ ɧɘŬɠ Űɠ ´ Ůɟ ɘ´ Ű ůŬɠ Ůɘůɘ Űűɐɠ ɘŬɘ ɔɘŬ Űɛɡɠ 2 Ű´ ɛɡɠ ɡɘɘɩ ɜ, ɧ´ ɤ ɠ ůɡɘɘɣɔɖůŬ Ŭ ɧ Űɛɡɠ ɘɧɛ ɓɛɡɠ ŭɑɛɜŰŰɘ ůŰɛ Ʉɟ Λɟ Λɇ ¢ ɀ ɟ ɟ .

3.4 [illegible]

[illegible]:

- [illegible] n [illegible], θ_1, θ_2 [illegible] R = 0.2145 m, [illegible] $d\theta=(\theta_2-\theta_1)/(n-1)$. [illegible] i [illegible], [illegible] i = 1, 2,....., n [illegible] $\theta_i = \theta_1 + (i-1)\, d\theta$
- [illegible] $u_i = -u_{xx,i}\cos\theta_i - u_{yy,i}\sin\theta_i$, [illegible] u_{xx}, u_{yy} [illegible].
- [illegible] c = 1 [illegible] i∈[2,n-1], c = 1/2 [illegible] i = 1 [illegible] c = 1/2 [illegible] i = n
- [illegible]:

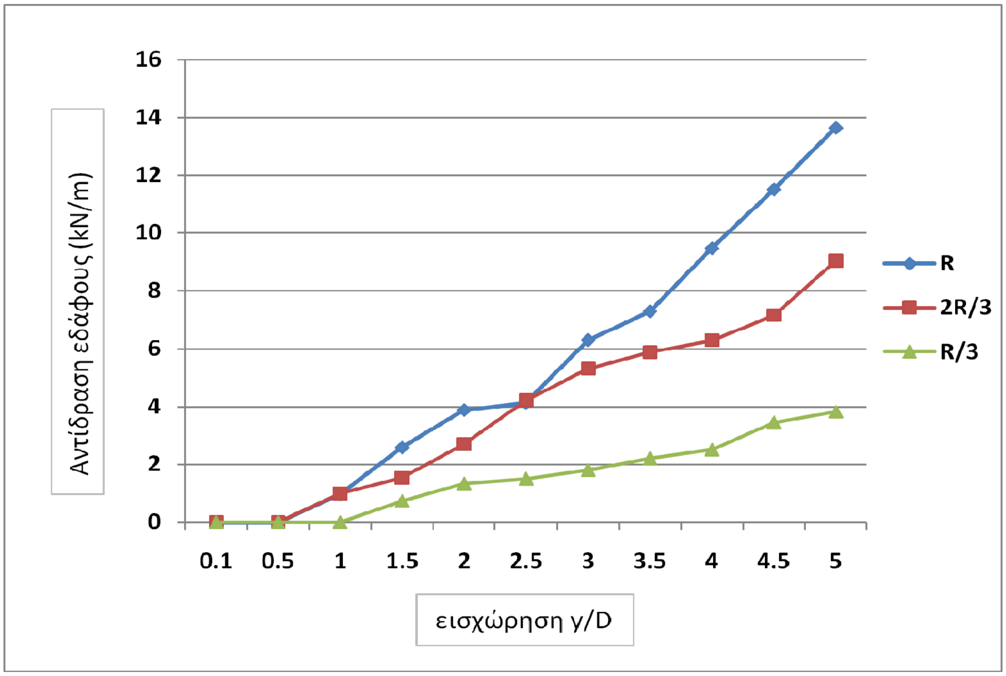
$$Fz = -\sum_{i=1}^{n} R\, c_i u_i \sin\theta_i\, d\theta$$

[illegible] "script" [illegible] Matlab. [illegible].

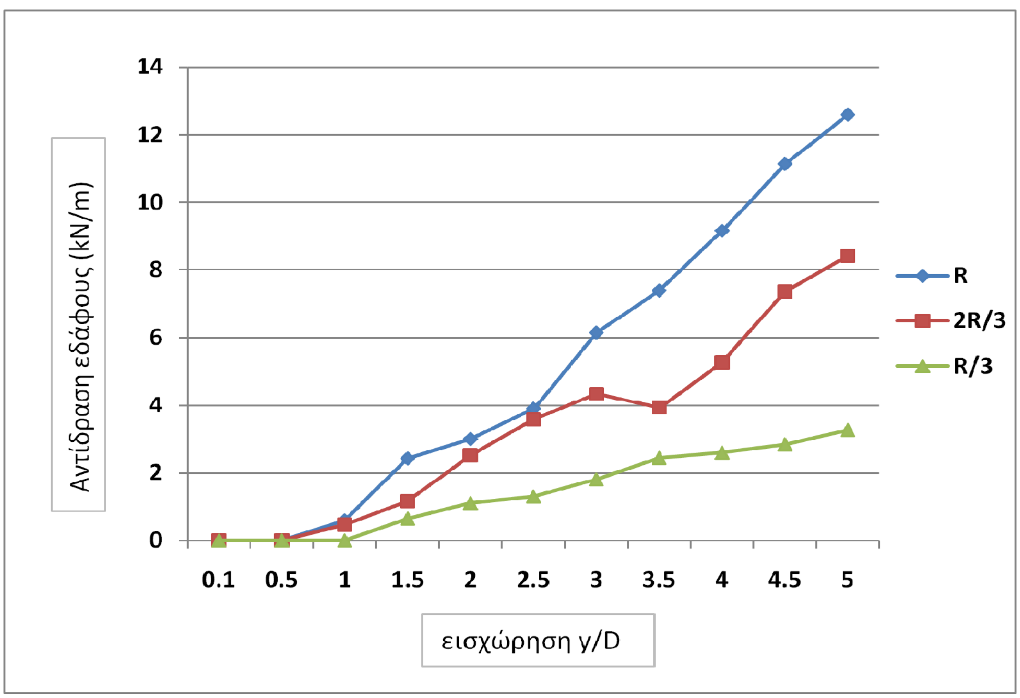
[illegible] (R/3 --> 2R/3 --> R). [illegible].

[illegible].

[illegible].



φэŸɔɟ Ŭɛ ɛŬ3.4.1: ɀ ŮŰŬɓɞɚɐ Űɖɠ Ŭɜ Űɑŭɟ Ŭůɖɠ Űɝg ŮŭŸűɞgɠ
ɛŮŰɞ ɓŸɗɞɠ Ůɚůɢ ɟ ɖůɖɠ Űɝg riser ůŮɛ ŬɚŬɘ ɧ ɠgɞ-Ŭɟ ɔɚɥ ŭŮɠ ɏŭŬűɞɠ



φэŸɔɟ Ŭɛ ɛŬ3.4.2: ɀ ŮŰŬɓɞɚɐ Űɖɠ Ŭɜ Űɑŭɟ Ŭůɖɠ Űɝg ŮŭŸűɞgɠ
ɛŮŰɞ ɓŸɗɞɠ Ůɚůɢ ɟ ɖůɖɠ Űɝg riser ůŮɛ ŬɚŬɘ ɧ Ŭɛ ɛ ɞ-Ŭɟ ɔɚɥ ŭŮɠ ɏŭŬűɞɠ

[illegible] < D, [illegible] Phase 2 [illegible]

[illegible] y: [2D, 2.5D] [illegible] R [illegible] 2R/3, [illegible]

4. [illegible] riser [illegible].

[illegible] CON3DF [illegible] TDP.

4.1. [illegible]

[illegible] riser [7], [illegible] (Lagrangian) [illegible] Lagrangian [illegible], s. [illegible] s=0 [illegible] riser [illegible] s=L, [illegible] L [illegible] riser.

[illegible]

[illegible] riser [illegible]:

- ***[illegible]***
- ***[illegible]***
- ***[illegible]***
- ***[illegible]** EA/L **[illegible]***
- ***[illegible]***
- ***[illegible] «[illegible]» [illegible]***
- ***[illegible]***

[illegible] riser [illegible]

[illegible]

- [illegible]
- [illegible] (E. T. Chatjigeorgiou, "A finite differences formulation for the linear and nonlinear dynamics of 2D catenary risers", Ocean Engineering, 2008) [illegible]
- [illegible] riser, [illegible]
- [illegible]
- [illegible] riser [illegible]

4.1.1. [illegible]

[illegible] riser [illegible]:

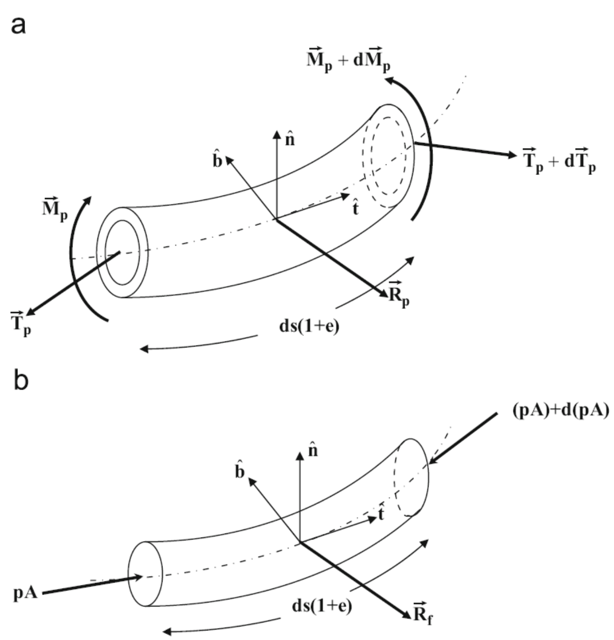
- [illegible]
- m, [illegible] riser [illegible]
- m_a, [illegible]
- w_o, [illegible] riser [illegible]
- d_o, [illegible]
- [illegible]
- Ip, [illegible]
- I, [illegible]
- $[illegible]_c$, [illegible]
- E, [illegible] Young
- G, [illegible]

To ΄ Ǘʝ Ǚε ɞʝ ΰ̋ɤ εɏɜɞ ǚɘǕΰ̋ɞʝ ɘɧ εɐǝɞɕ Ůɜɧɕ΄ Ů Ǘʝ Ǚůεɏɜɞɡ Ǘɛεɐε ǗΰǕɕǗɡ riser ΄ ʝ ɞůǚɘʝ ɶǗǗǕ ɘ Ǚ ɧ Ǘɖ ůɢɏůɖ:

$$dp = ds\,(1+e), \qquad (1)$$

ɧ΄ ɞɡ ds Ǘɛ ǓɜǕ̋ůǗɛɜɢɜ Ǚ Ǘʝ Ǚε ɧʝ ΰ̋ɤ Ǘɛ εɐǝɞɕ Ǘɛɡ ůǗɛɜɢǗɛɡ, e ɖ Ǔɜɞɜɘɐ ΄ Ǘʝ Ǚε ɧʝ ΰ̋ɤ ůɖ ǝǓɘ s ɖ Ǘɛ΄ ɘɐ ůɡɜǗǗǗǓεɏɜɖ.

ȳ ǝǗɕ ɞɘ εǗǗǗɓǝɖǗɏɕ ǓɜǕ̋ɏʝ ɞɜǗǕɘ ůǗɛ Ǘɛ΄ ɘɧ ůɨ ůǗɖε Ǚ ůɡɜǗǗǗɓεɏɜɤ ɜ ΄ ɞɡ ɞʝ ɶɞɡɜ Ǘǚ εɞɜǙǚɘǙɖǙ ǚɘǓɜɨ ůεǙǗǗ Ǘɖɕ ǗΰǙ Ǘɛεɏɜɖɕ, Ǘɖɕ ǝǙɖɏǗɛɡ ǝǓɘ Ǘɖɕ ǚɘǙɖɏǗɛɡ, $\vec{t},\vec{n},\vec{b}$ (ůɢɐε Ǚ 4.1.1.).



***Ɇɢɐε Ǚ** 4.1.1.*

*a. **ɶɡɜƳεǗɕǝǓɘʝ ɞ΄ ɏɕůǗɛ ΄ Ǘʝ Ǚε ɞʝ ΰ̋ɤ εɏɜɞ ůǗɛɜɢǗɛ Ǘɛɡ** riser*

*b. **ɶɡɜƳεǗɕůǗɛɜ ɧɔǝɞ Ǘɛɡ ɡɔʝ ɞɨ ΄ ɞɡ ǚɘǗǗʝ ɏɢǗɛǗɛ ůǗɛɜɢǗɛ Ǘɛɡ** riser*

[illegible]

$$\vec{T}_p = T\vec{t} + S_n\vec{n} + S_b\vec{b}$$

$$\vec{M}_p = M_1\vec{t} + M_2\vec{n} + M_3\vec{b} \qquad (2)$$

[illegible] T, [illegible] S_n [illegible] (in-plane) [illegible] S_b [illegible] (out-of-plane) [illegible] ζ_1 [illegible] ζ_2 [illegible] (out-of-plane) [illegible] ζ_3 [illegible] riser (in-plane) [illegible] $p\bar{A}t$ [illegible] 4.1.1.b. [illegible].

[illegible]:

$$\sum \vec{R}_p = \vec{R}_{pw} + \vec{R}_{pa} + \vec{R}_{pd} \qquad (3)$$

$$\sum \vec{R}_f = \vec{R}_{fw} \qquad (4)$$

[illegible] R_{pw} [illegible] R_{pa} [illegible] R_{pd} [illegible].

[illegible].

4.1.2. ǰ ɟ ɞɜɘɏǥɘ Ǚǰ ɤ ɟ ɘɏǥ ´ Ǚ Ƴɔɤɔɞɘ

¢ ǓɞƳɚǥůɖ Ǘɤɜ ǥɚɘɩɜ ´Ǚ ǓɩɔɤɜǗɶǓɘ ´ǘɑɚɞɚɖ ɚƕɔɤ Ǘ ɘɞɔɐǥ Ǘɞǥ Langrangian ůǥůǗɛǓǗɞǥ ůǥɜǗǗǓɛɏɜɤɜ, Ǘɞ ɞ´ɞɶ ǗɶǓɘ ɕɟɞɜɘƳ ɚǓɘ ɕɤɟɘƳ ɛǗǗǓǓɘɚƕɛǗɞ. Ƀɘ ´Ǚ ƳɔɤɔɞɘǗɘůɟƳɞɜǗǓɤǥ´ɟɞǥɏɜǓǗǥɕǓɶ ǔɘƳɜǥůɛǓ $\vec{G}$:

$$\vec{G} = G_1\vec{t} + G_2\vec{n} + G_3\vec{b} \tag{5}$$

$$\frac{D\vec{G}}{Ds} = \frac{\partial \vec{G}}{\partial s} + G_1\frac{\partial \vec{t}}{\partial s} + G_2\frac{\partial \vec{n}}{\partial s} + G_3\frac{\partial \vec{b}}{\partial s} \tag{6}$$

Ǝ´ɑůɖǥ, Ǘɞ ǔɘƳɜǥůɛǓ ´ǙɘůǗɞůɐǥ Darboux, $\vec{\Omega}$, ɔɘǓ ɚǓɛ´ɨɚɖ ůǗɞ ɕɩɟɞ, Ǘɞ ɞ´ɞɶ, Ǔɘɟɘɩ ǥ, Ǘůɟ ƳɞǗɘǗɖɜ ɚǓɛ´ ǥɚƕǗɖǗǓǗɞǥ ůǗɞɕǗɞǥ, ǗɶǓ:

$$\vec{\Omega} = \Omega_1\vec{t} + \Omega_2\vec{n} + \Omega_3\vec{b} \,. \tag{7}$$

ŌǗůɘ, ɔɘǓ Ǘɖɜ ǓɞƳɚǥůɖ Ǘɤɜ ɕɤɟɘɩɜ ´ǙɓɩɔɤɜǗɤɜ ɛɞɜǓǔɘǓɤɜ ǔɘǓɜǥůɛƳǗɤɜ ɖǓ ɕɖůɶɞ´ɞɖɖɞɨɜ ɞɘ ůǥɛɛǗɟɘɏǥɘƕǗɖǗǥǗɞǥ ǔɘǓɜɨ ůɛǓɞǥ Darboux (M.S. Rahman, 1994), Ǘ ɞɛɏɜɤǥ:

$$\frac{\partial \vec{t}}{\partial s} = \vec{\Omega}\times\vec{t}\,, \quad \frac{\partial \vec{n}}{\partial s} = \vec{\Omega}\times\vec{n} \quad \text{ɚǓɘ} \quad \frac{\partial \vec{b}}{\partial s} = \vec{\Omega}\times\vec{b}$$

ɚǓɘɖ ɕɤɟɘɐ ´Ǚ Ƴɔɤɔɞǥ Ǘɞǥ $\vec{G}$ ɔɶǗǗ:

$$\frac{D\vec{G}}{Ds} = \frac{\partial \vec{G}}{\partial s} + \vec{\Omega}\times\vec{G} \tag{8}$$

ɆɢŮǗǿƳ ɛŮǗɖ ɕɟɞɜɘɐ ´ŬɟƳɔɤɔɞ Ǘǳg $\vec{G}$, Ǘǳ ɘůɞŭɨ ɜŬɛɞ Ǘǳg ŭɘŬɜɨ ůɛŬǗǳɠ Darboux ŮǳŬɜ Ǘǳ ŭɘƳɜgůɛŬůǗɟ ɞǘɐɠǗɖɠɘɚŬůɘɐɠŭgɜŬɛɘɐɠ, $\vec{\omega}$:

$$\vec{\omega} = \omega_1 \vec{t} + \omega_2 \vec{n} + \omega_3 \vec{b} \,, \tag{9}$$

ȳ ´ɞg ω_1, ω_2, ω_3 ɞɘŬɜǗǖůǗǳɢŮɠɔɤ ɜɘŬɘɏɠǗŬɞɨ ǗɖǗŮɠ.

ŌǗůɘ, ɖ ɕɟɞɜɘɐ ´ŬɟƳɔɤ ɔɞɠǗǳg ǗgɢŬǳg ŭɘŬɜɨ ůɛŬǗǳɠ $\vec{G}$, ɔɟƳǘŮǗŬɜ

$$\frac{D\vec{G}}{Dt} = \frac{\partial\vec{G}}{\partial t} + \vec{\omega}\times\vec{G} \tag{10}$$

ɇŬůǗǳɢŮŬǗɤɜ ŭɘŬɜgůɛƳǗɤɜ $\vec{\omega}$ ɘŬɜ $\vec{\Omega}$ ɛ´ɞɟɞɨɜ ɜŬŮǘɟŬůǗǳɨ ɜ ɤ ɠ´ɟɞɠǗǳɠɔɤ ɜɖŮɠ Euler, ǘ, ɗ ɘŬɜɣ [21, 22] ´ɞg ŮǳŬɜ, ɞgůɘŬůǗǿƳ ɞɘɔɤ ɜɖǗɠ ůǗɟ ɞǘɐɠ ɛŮǗŬɨ Ǘǳg ɘŬɟ ǗůɘŬɜɞɨ ɘŬɜ Ǘǳg ůɤ ɛŬǗǳ´Ŭɞɨ ɠůgůǗɛŬǗǳɠ ůgɜǗŮǗŬɛɏɜɤɜ:

$$\omega_1 = \frac{\partial\psi}{\partial t} - \frac{\partial\phi}{\partial t}\sin\theta$$

$$\omega_2 = \frac{\partial\theta}{\partial t}\cos\psi + \frac{\partial\phi}{\partial t}\cos\theta\sin\psi$$

$$\omega_3 = \frac{\partial\phi}{\partial t}\cos\theta\cos\psi - \frac{\partial\theta}{\partial t}\sin\psi$$

$$\Omega_1 = \frac{\partial\psi}{\partial s} - \frac{\partial\phi}{\partial s}\sin\theta \tag{11}$$

$$\Omega_2 = \frac{\partial\theta}{\partial s}\cos\psi + \frac{\partial\phi}{\partial s}\cos\theta\sin\psi$$

$$\Omega_3 = \frac{\partial\phi}{\partial s}\cos\theta\cos\psi - \frac{\partial\theta}{\partial s}\sin\psi$$

Ά´ αůđďʃ, Ǘǝ ŭэŸзgůεǓɟ ɞ´ ι з ε´ ɞɟ Ůά зǓɔɟ Ǘί Ǘάůgз Ǘɟ Ǘɐ ůǕǝ Ǘɤ з ´ Ǘɟ Ǘɛ ɏǗɟ ɤ з əǓε´ gəɧǗďǗǗʃ ɤ ʃ Ůǝɐʃ:

$$\overrightarrow{M_p} = M_1\vec{t} + M_2\vec{n} + M_3\vec{b} = GI_p\Omega_1\vec{t} + EI\Omega_2\vec{n} + EI\Omega_3\vec{b} \quad (12)$$

4.1.3. ɖɡз Ǔε эɐ эůɞɟɟ ɞ´ đǓ Ǘǝg ůǗǝэɕǗǝɡ Ǔɔɤ ɔɧʃ

4.1.3.1. ɟ ŭɟ Ǔз ǕэǓə ɏʃ Άзэůι ůǕǝʃ

¢ Ǖǝαůɤ ůď Ǘǝg ? ɧεɞg Ǘǝg Newton ůǗǝ ´ Ǘɟ Ǔε ɞɟ ǘɤ ε ɏзɞ Ǘε ɐε Ǔ Ǘǝg Ǔɔɤ ɔɞɨ ůǕůgзŭgǗůεɧ εǕ Ǘďз Ǘɟ ɕɐ ŭэǗǗɐɟ ďůďʃ Ǘďʃ ε Ÿɛ Ǘʃ ɔɟ ŸίǕǗǓз

$$m\frac{D\vec{V}_p}{Dt} = \frac{D\vec{T}_p}{Ds} + \sum \vec{R}_p(1+e) \quad (13)$$

ɟ зǓəɨ ɞзǗǗʃ Ǘǝʃ gəэɏʃ ´ Ǘɟ Ǔɔι ɔɞgʃ ůǗǝ Ǘǝ´ эɧ, əǗǗŸ Ǘď ŭэǕɨ đgзůď Ǘďʃ ´ Ǘɟ Ǔε ɧɟ ǘɤ ůďʃ, ůɨ ůǗďεǓůgзǗǗǕǗɔε ɏзɤ з əǓε ɓŸзɞgεǕ

$$m\left(\frac{\partial\vec{V}_p}{\partial t} + \vec{\omega}\times\vec{V}_p\right) = \frac{\partial\vec{T}_p}{\partial s} + \vec{\Omega}\times\vec{T}_p + (\vec{R}_{pw} + \vec{R}_{pa} + \vec{R}_{pd})(1+e), \quad (14)$$

ɧ´ ɞg $\vec{V}_p$ Ǘǝ ŭэŸзgůεǓ Ǘďʃ ǗǗɕɨ ǗďǗǗʃ ůǗǝ Ǘǝ´ эɧ ůɨ ůǗďεǓ ůgзǗǗǕǗɔε ɏзɤ з, $\vec{V}_p = u\vec{t} + v\vec{n} + w\vec{b}$.

4.1.3.2. ȽůɞɈɈ ɘ´ ɗŬɈ ɘ´ ɩ ɜ

₵ ɘůɞɈɈ ɘ´ ɗŬɈ ɘ´ ɩ ɜ Ůəűɉ Ÿɛ ŮŰŰə ɛ Ůɕɉ ɐůɖ Űɖɠ Ůǝɑůɤ ůɖɠ [22]:

$$\frac{1}{1+e}\frac{D}{Dt}[\rho_c I\vec{\omega}] = \frac{1}{(1+e)^2}\frac{D\overrightarrow{M}_p}{Ds} + \vec{t}\times\vec{T}_p(1+e) \tag{15}$$

ÿ ´ɕɡ $ɟ_c$Ƚ Ůɞ Ŭə ŭəŬɒɩ ɜɚɕɠ ´ ɶŬə Ŭɠ 3X3 ɛ Ůů Űɛɘɕ ŮŬ əɨ ɟə Ŭɠ ŭə Ŭɒɤ ɜɶɡ ($ɟ_c I_p$, $ɟ_c I$, $ɟ_c I$). ȾŬŰɧ´ɞ, ŬɞŬəɨ ɞɜŰŰɠ Űɠ ɡəɚɣɠ ´ Ŭɟ Ŭɒɩ ɔɞɡɠ, əŬɛ ɓŸɜɞɡɛ Ů

$$\frac{\rho_c I}{1+e}\left(\frac{\partial\vec{\omega}}{\partial t} + \vec{\omega}\times\vec{\omega}\right) = \frac{1}{(1+e)^2}\left(\frac{\partial\overrightarrow{M}_p}{\partial s} + \vec{\Omega}\times\overrightarrow{M}_p\right) + \vec{t}\times\vec{T}_p(1+e) \tag{16}$$

4.1.3.3. Ɇɡɜɗɐə Űɠ ůɡɛ ɓəɓŬůŰɛɨ

ɇɞ ŭəŬűɞɟɚɧ Űɛ ɐɛŬ Űɛɡ Ŭɒɤ ɔɞɨ ɗŮɤ ɟ ŮɑŰŰə ɧŰə ŭŮɜ ´ Ŭɟ ɞɡůəŸɛ Ůə Ůůɡɜɣɕ ŮəŮɠ. Ⱥ´ ɞɛɏɜɤ ɡ, Űɛ ŭəŸɜɡůɛ Ŭ Ŭ ɧ Űɖɜ Ŭɟ ɕɐ Űɧůɞ Űɛɡ ůŰɛɚɕŮɛɡ Ŭɒɤ ɔɧɠ ɧůɞ əŬə Űɛɡ ůŰɛɚɕŮɛɡ Űɛɡ ɡɔɟɞɨ, $\vec{r}(s,t)$, ɗŬ ŮɞŬə ůɡɜŮɛɐɠ ůɡɜŸɟ Űɖůɖ əŬə Űɤ ɜ 2 ŬɞŮɝŸɟ ŰɖŰɤ ɜ ɛ ŰŰŬɓəɖŰ ɜ ɕɩ ɟɕɡ əŬə ɕɟ ɧɜɞɡ, s əŬə t, ŬɞŰɑ ůŰɛɚɕŬ. ɇɞ ɔŮɞɜɧɠ Ŭɡ Űɧ ɛ´ ɕɟ Ůɑ ɜŬ Ůəűɉ Ŭů ŰŰŰ ɛ ŮŰɖɜ ɘůɧŰɖŰŰ:

$$\frac{D}{Dt}\left[\frac{D\vec{r}}{Ds}\right] = \frac{D}{Ds}\left[\frac{D\vec{r}}{Dt}\right] \tag{17}$$

ÿ ´ɤ ɠ ű ŬɞŮŰŰə ůŰɖɜ Ůəɧɜ Ŭ 4.1.1.a:

$$\frac{D\vec{r}}{Ds} = (1+e)\vec{t} \quad [illegible] \quad \frac{D\vec{r}}{Dt} = \vec{V}_p$$

[illegible], $e = T/EA$, [illegible]:

$$\frac{1}{EA}\frac{\partial T}{\partial t}\vec{t} + (1+e)\vec{\omega}\times\vec{t} = \frac{\partial \vec{V}_p}{\partial s} + \vec{\Omega}\times\vec{V}_p \qquad (18)$$

4.1.4 [illegible]

4.1.4.1. [illegible]

[illegible] 4.1.1.b. [illegible]:

$$M\frac{D\vec{V}_f}{Dt} = \frac{D(-pA\vec{t})}{Ds} + \sum \vec{R}_f(1+e) \qquad (19)$$

[illegible] $\vec{V}_f = U\vec{t} + v\vec{n} + w\vec{b}$ [illegible]

$$m\left(\frac{\partial \vec{V}_f}{\partial t} + \vec{\omega}\times\vec{V}_f\right) = \frac{\partial(-pA\vec{t})}{\partial s} + \vec{\Omega}\times(-pA\vec{t}) + \vec{R}_{fw}(1+e) \qquad (20)$$

4.1.4.2. [illegible]

[illegible]

$$\frac{D}{Dt}[(1+e)\vec{t}\,] = \frac{D\vec{V}_f}{Ds} \tag{21}$$

[illegible] 4.1.1.b. [illegible]

$$(1+e)\vec{\omega}\times\vec{t} = \frac{\partial \vec{V}_f}{\partial s} + \vec{\Omega}\times\vec{V}_f + \frac{1}{EA}\frac{\partial pA}{\partial t}\vec{t} \tag{22}$$

[illegible]

[illegible] $\frac{1}{EA}\frac{\partial pA}{\partial t}\vec{t}$ [illegible]

4.1.5 [illegible]

[illegible] (14), (16), (18), (20), (22).

ÆǝůƳɔɞɜŰŰƌ Űďɜ (22) ůŰďɜ (20) ǝŬɛ ƃƳɜɞǥɛ ŮŰď ŭǝŬŰɞɈǝǝ Ůǝůɤ ůď ŭǥɜŬɛǝǝƌ ǝůɞɈɈɞ´ďŬƌ Űǥ ǥɔɈɞɨ :

$$
\begin{aligned}
& m\frac{\partial \vec{V}_f}{\partial t}+\frac{MU}{1+e}\left(\frac{\partial \vec{V}_f}{\partial s}+\vec{\Omega}\times\vec{V}_f+\frac{1}{EA}\frac{\partial pA}{\partial t}\vec{t}\right)+M(v*\vec{\omega}\times\vec{n}+w*\vec{\omega}\times\vec{b})= \\
& -\frac{\partial pA}{\partial t}\vec{t}-pA*\vec{\Omega}\times\vec{t}+\vec{R}_{fw}(1+e),
\end{aligned}
\qquad (23)
$$

ƬŬŰ´ǝ, ŬɈɞɞɜŰŰƌ Űƌ (14) ǝŬǝ (23) ůǥɜŭǥƳɞɜŰǝ ď ŭǥɜŬɛǝǝ ǝůɞɈɈɞ´ďŬ Űǥ Ŭɤɔɞɨ ǝŬǝ Űǥ ǥɔɈɞɨ ǝŬǝ´ɈɞǝɨŰǝ ď ŬɈŬɜŮǝŬǝ Ůǝůɤ ůď Űǥ ůǥůŰɛŬŰƌ:

$$
\begin{aligned}
& m\left(\frac{\partial \vec{V}_p}{\partial t}+\vec{\omega}\times\vec{V}_p\right)+M\frac{\partial \vec{V}_f}{\partial t}+\frac{MU}{1+e}\left(\frac{\partial \vec{V}_f}{\partial s}+\vec{\Omega}\times\vec{V}_f+\frac{1}{EA}\frac{\partial pA}{\partial t}\vec{t}\right)+ \\
& M(v*\vec{\omega}\times\vec{n}+w*\vec{\omega}\times\vec{b})=\frac{\partial T_p}{\partial s}+\Omega\times T_p-\frac{\partial pA}{\partial s}\vec{t}-pA\Omega\times\vec{t}+ \\
& (\vec{R}_{pw}+\vec{R}_{fw}+\vec{R}_{pa}+\vec{R}_{pd})(1+e),
\end{aligned}
\qquad (24)
$$

4.1.6 ǝŬǝŮɛ ďɛɏɜŮƌ ŭǥɜƳɛ Ůƌ

ɄɈǝ ´ɈɞƃɞɨɛŮ ůŰď ɔɈŬǝ Űǥ ŰǝǝɞɨůǥůŰɛŬŰƌ ŭǝŬŰɞɈǝɩ ɜ Ůǝǝɩ ůŮɜ ´ɞǥ ďŬ ´ɈɞǝɨɣɞǥɜŬɞɨ ŬɜŬ ŰǥɕďɞɨɜŰŬ ŬɜŰůŰǝɕŬ Ŭ ɞŰǝɏůɛŬŬ Ůɜ (16), (18) ǝŬǝ (24), ŮɜŬǝ Ŭ ŬɈŬďŰďŰď ď Ů ŮǝɛɔďůďŰɜ ůɞɏůŮɜ ´ɞǥ ´ŮǝǝɈƳŰɞǥɜ Űƌ ŭǝŬɜŮɛďɛɏɜŮƌ Ůǝɤ ŰɈǝǝƌ ŭǥɜƳɛŮƌ:

$$
(\vec{R}_{pw}+\vec{R}_{fw})(1+e)=-(w_o+Mg)\sin\phi\cos\theta*\vec{t}-(w_o+Mg)\cos\psi*\vec{n}-(w_o+Mg)\sin\phi\sin\theta*\vec{b}
$$

$$
\vec{R}_{pa}(1+e)=-m_a\frac{\partial V_{2r}}{\partial t}\vec{n}-m_a\frac{\partial V_{3r}}{\partial t}\vec{b}
$$

$$
\vec{R}_{pd}(1+e)=R_{dt}\vec{t}+R_{dn}\vec{n}+R_{db}\vec{b}
$$

$$R_{dt} = -1/2\rho d_o C_{dt} u_{1r} \left| u_{1r} \right| \sqrt{1+e}$$

$$R_{dn} = -1/2\rho d_o C_{dn} u_{2r} \sqrt{{u_{2r}}^2 + {u_{3r}}^2}\sqrt{1+e}$$

$$R_{db} = -1/2\rho d_o C_{db} u_{3r} \sqrt{{u_{2r}}^2 + {u_{3r}}^2}\sqrt{1+e}, \qquad (25)$$

[illegible] u_{1r}, u_{2r}, u_{3r} [illegible] (u, v, w). [illegible] R_{dt}, R_{dn}, R_{db} [illegible] Morison [illegible] C_{dt}, C_{dn}, C_{db} [illegible].

4.1.7 [illegible]

[illegible] (16), (18) [illegible] (24) [illegible]

- **[illegible]:**

$$m\frac{\partial u}{\partial t} + (M+m)(\omega_2 w - \omega_3 v) + M\frac{dU}{dt} + \frac{MU}{1+e}(\Omega_2 w - \Omega_3 v + \frac{1}{EA}\frac{\partial pA}{\partial t}) =$$
$$\frac{\partial (T-pA)}{\partial s} + S_b\Omega_2 - S_n\Omega_3 - (w_o + Mg)\sin\phi\cos\theta + R_{dt} \qquad (26)$$

$$(m+M)\frac{\partial v}{\partial t} + m(\omega_3 u - \omega_1 w) + M\omega_1 w + \frac{MU}{1+e}\frac{\partial v}{\partial s} + \frac{MU^2}{1+e}\Omega_3 - \frac{MU}{1+e}\Omega_1 w +$$
$$m_a\frac{\partial v_{2r}}{\partial t} = \frac{\partial S_n}{\partial s} + \Omega_3(T-pA) - \Omega_1 S_b - (w_o + Mg)\cos\phi + R_{dn} \qquad (27)$$

$$(m+M)\frac{\partial w}{\partial t}+m(\omega_1 v-\omega_2 u)+M\omega_1 v+\frac{MU}{1+e}\frac{\partial w}{\partial s}+\frac{MU^2}{1+e}\Omega_2-\frac{MU}{1+e}\Omega_1 v+$$
$$m_a\frac{\partial v_{3r}}{\partial t}=\frac{\partial S_b}{\partial s}-\Omega_2(T-pA)+\Omega_1 S_n-(w_o+Mg)\sin\phi\sin\theta+R_{db} \quad (28)$$

- **Ӕзэůι ůŮӄɠůɡɛ ɓэɓŬůŰɛɨ :**

$$\frac{1}{EA}\frac{\partial T}{\partial t}=\frac{\partial u}{\partial s}+\Omega_2 w-\Omega_3 v \quad (29)$$

$$(1+e)\omega_3=\frac{\partial v}{\partial s}+\Omega_3 u-\Omega_1 w \quad (30)$$

$$-(1+e)\omega_2=\frac{\partial w}{\partial s}+\Omega_1 v-\Omega_2 u \quad (31)$$

- **Ӕзэůι ůŮӄɠэůɞɟɟ ɞ´ ɗŬɠɟ ɞ´ ι з:**

$$(1+e)\rho_c I_p\frac{\partial\omega_1}{\partial t}=GI_p\frac{\partial\Omega_1}{\partial s} \quad (32)$$

$$(1+e)\rho_c I\frac{\partial\omega_2}{\partial t}=EI\frac{\partial\Omega_2}{\partial s}+(GI_p-EI)\Omega_1\Omega_3-S_b(1+e)^3 \quad (33)$$

$$(1+e)\rho_c I\frac{\partial\omega_3}{\partial t}=EI\frac{\partial\Omega_3}{\partial s}+(EI-GI_p)\Omega_1\Omega_2-S_n(1+e)^3 \quad (34)$$

Ƀэ Ůэůι ůŮӄɠ (32) ɏɤ ɠ (34) ´ ɟɞɏɘɡɣŬз ɗŮɤ ɟ ι зŰŬɠ ɧŰэ ɞэ ɧɟɞэ *ӔⱠ* ɘŬэ GI_p ůɞŬэ ŬзŮӄɎ ŰɖŰɞэ Űɖɠ ůɡзŰŰŬɓɛɏзɗɠ s. Ƀэ ´ŬɟŬ Ɏзɤ Ůэůι ůŮӄɠ (26-34) ůɡзɗɏŰɞɡз ůɨůŰɖɛŬ 9 ɀ Ůɟэι з ɕэŬŰɞɟэι з Ӕзэůι ůŮɤ з ɛŮ13 Ŭзι ůŰɞɡɠ, Űɠ ŭɡзŬɛэɏɠ ůɡзэůŰ ůŮɠ:

$$T,\ pA,\ S_n,\ S_b,\ u,\ v,\ w,\ \omega_1,\ \omega_2,\ \omega_3,\ \Omega_1,\ \Omega_2,\ \Omega_3.$$

Ƀэɔɤзэ Ŭэɏɠ ŰŬɨ ŰɖŰŮɠ, ɤ ɘŬэ ɞэ Űɞ´эɏɠ ɘŬɛ´ɡэɧŰɖŰŮɠ, q , ε´ɞɟɞɨ з зŬ ŮэŰɟŬŰŰɞɨ з ɤ ɠ ´ɟɞɠ Űɠ ɔɤ зɗŮɠ Euler, ű, ɗ, ɣ. ŌŰŰэ, ŬзŰэ ŬɗэůŰ зŰŰɠ ůŮɠ (26-34) Űɠ 3 ´ɟι ŰŰɠ Ůэůι ůŮɠ Űɤ з (11) əŬǝ ´ ɟɞůɗɏŰɛɜŰŰɠ ůŰɛ ůɨ ůŰɖɛŬ Űɠ 3 ŰŰǝŮɠŰŰɗŮɠ Ůǝəůɩ ůŬɠ Űɤ ɜ (11) ´ ɟɞəɨ ´ ŰŮǝ ůɨ ůŰɖɛŬ 12 Ůǝəůɩ ůŬɤ ɜ ɛŮ13 Ŭɔɜɩ ůŰɛɢɠ, Űɠ ´ ɞůɧŰɖŰŰɠ:

$$T,\ p\boldsymbol{J}\ ,\ S_n,\ S_b,\ u,\ v,\ w,\ \boldsymbol{\ddot{u}},\ \boldsymbol{d},\ \boldsymbol{\gamma},\ \boldsymbol{q}_1,\ \boldsymbol{q}_2,\ \boldsymbol{q}_3.$$

ŢŬŰɧ´ɞ, ɗŬɤ ɟɩ ɜŰŰɠ ůŰŰɗŮɟ ɐ ɟɞɐ ŮɜŰɧɠ Űɛɢ Ŭɔɤ ɔɞɨ ɗŬ ɘůɢɨ Ůǝ $dU/dt = 0$ əŬǝ $d(pA)/dt = 0$. Ƀ´ ɧŰŮ´ Ŭɟ ŬǝŮɾ ŮŰŰǝ ɖ (26) əŬǝ ɖ (29) ɔɞɞɜŰŰǝ:

$$\frac{1}{EA}\frac{\partial T_e}{\partial t} = \frac{\partial u}{\partial s} + \Omega_2 w - \Omega_3 v,$$
$$T_e = T - pA$$

ȺəůƳɔɞɜŰŰɠ Űɖɜ ɑɘŬ ´ ɞůɧŰɖŰŰ, T_e ůŰɠ (26-28), Ů ɘŰɡɔɢƳɜŮŰŰǝ ɖ Ŭ Ŭǝɞəɾɐ Űɤ ɜ T əŬǝ pA əŬǝ ´ ɟɞəɨ ´ ŰŮǝ ůɨ ůŰɖɛŬ 12 Ůǝəůɩ ůŬɤ ɜ ɛŮ 12 Ŭɔɜɩ ůŰɛɢɠ. ɟ ɜ, Ů ɘ´ əɏɞɜ ɔɞŮǝ ´ Ŭɟ Ƴəɖɣ ɖ Űɖɠ ůŰɟɏɣ ɖɠ, ɖ (32) ɛ´ ɞɟŮɑɜŬ ŬɛŮǝɖɗŮɑ, ɧ´ ɤ ɠ, Ů ɑůɖɠ əŬǝ ɞɘ ɧɟ ɞɘ ůŰɟ Ů Űǝɐɠ ŬǝŬɛ ɣ ɗŬɠ. ɀ ´ ɞɟŮɑ Ů ɑůɖɠ ɜŬ Ŭ ɞŭŮǝɢɗŮɑ ɧŰǝ ɔɘŬ ɢŬǝɨ ɓŭɞɛɢɠ Ŭɔɤ ɔɞɨ ɠ ɞɘ ůŰɟ Ů Űǝɞɑ Űɟ ŬɜŮɘŬǝɞɑ ɧɟɞɘ ŮɞŬǝ ŬɛŮǝɖŰɏɞɘ ůŮ ůɢɏůɖ ɛŮ Űɛɢ ɧɟɛɢɠ əŬɛ´ Űǝɐɠ ŬǝŬɛ ɣ ɗŬɠ [22]. Ⱥ´ ɞɛɏɜɤ ɠ, ɛ´ ɞɟŮɑ ɜŬ ´ Ŭɟ Ŭǝɖűɗ Ůɑ ɞ ŭŬǝɧɠ ɧɟ ɞɠ Űɖɠ (16) ɢɤ ɟ ɑɠ Ŭ ɩ əŮǝŬ Ŭǝɟ ɐ Ůǝ Ŭɠ. Ⱥ´ ɘ´ əɏɞɜ, ŰŬ ůŰɛɔŮǝŬ Űɤ ɜ ŭɘŬɜɢůɛƳŰɤ ɜ ɔɤ ɜɘŬǝɐɠ ŰŰɨ ŰɖŰŰɠ əŬǝ əŬɛ´ ɢəɧŰɖŰŰɠ ɔɞɞɜŰŰǝ, ŬɜŰɑůŰɛɔŬ:

$$\begin{bmatrix} \omega_1 & \omega_2 & \omega_3 \end{bmatrix} = \begin{bmatrix} -\dfrac{\partial \phi}{\partial t}\sin\theta & \dfrac{\partial \theta}{\partial t} & \dfrac{\partial \phi}{\partial t}\cos\theta \end{bmatrix}$$

$$\begin{bmatrix} \Omega_1 & \Omega_2 & \Omega_3 \end{bmatrix} = \begin{bmatrix} -\dfrac{\partial \phi}{\partial s}\sin\theta & \dfrac{\partial \theta}{\partial s} & \dfrac{\partial \phi}{\partial s}\cos\theta \end{bmatrix}$$

ɟ ´ ɧ Űɖ ŭŬɨ Űɟ ɖ ŭɘŬɜɢůɛŬŰɐɐ ɘůɧŰɖŰŰ ůɢɜƳɔŮŰŰǝ ɧŰǝ $\boldsymbol{q}_1 = -\boldsymbol{q}_3\ tan\boldsymbol{d}$.

Ʉəɏɞɜ, ɖ ŰŮǝəɐ ɛɞɟűɐ Űɤ ɜ Ůǝəůɩ ůŬɤ ɜ ɗŬ ŮɞŬǝ:

$$\frac{\partial T_e}{\partial s} + S_b\Omega_2 - S_n\Omega_3 - (w_o + Mg)\sin\phi\cos\theta + R_{dt} - m\frac{\partial u}{\partial t}$$
$$-(m+M)(w\frac{\partial \theta}{\partial t} - v\frac{\partial \phi}{\partial t}\cos\theta) - \frac{MU}{1+e}(\Omega_2 w - \Omega_3 v) = 0 \tag{35}$$

$$\frac{\partial S_n}{\partial s} + \Omega_3(T_e - S_b\tan\theta) - (w_o + Mg)\cos\phi + R_{dn} - (m+M)\frac{\partial v}{\partial t}$$
$$-m\frac{\partial \phi}{\partial t}(u\cos\theta + w\sin\theta) - Mw\frac{\partial \phi}{\partial t}\sin\theta - \frac{MU}{1+e}\frac{\partial u}{\partial s} - \frac{MU^2}{1+e}\Omega_3 \tag{36}$$
$$-\frac{MU}{1+e}w\Omega_3\tan\theta - m_a\frac{\partial v}{\partial t} = 0$$

$$\frac{\partial S_b}{\partial s} - \Omega_2 T_e - \Omega_3 S_n\tan\theta - (w_o + Mg)\sin\phi\sin\theta + R_{db} - (m+M)\frac{\partial w}{\partial t}$$
$$-m(\frac{\partial \phi}{\partial t}v\sin\theta + u\frac{\partial \theta}{\partial t}) - Mv\frac{\partial \phi}{\partial t}\sin\theta - \frac{MU}{1+e}\frac{\partial w}{\partial s} + \frac{MU^2}{1+e}\Omega_2 \tag{37}$$
$$+\frac{MU}{1+e}v\Omega_3\tan\theta - m_a\frac{\partial w}{\partial t} = 0$$

$$\frac{\partial u}{\partial s} + \Omega_2 w - \Omega_3 v - \frac{1}{EA}\frac{\partial T_e}{\partial t} = 0 \tag{38}$$

$$\frac{\partial v}{\partial s} + \Omega_3(u + w\tan\theta) - (1+e)\frac{\partial \phi}{\partial t}\cos\theta = 0 \tag{39}$$

$$\frac{\partial w}{\partial s} + \Omega_3 v\tan\theta - \Omega_2 u + (1+e)\frac{\partial \theta}{\partial t} = 0 \tag{40}$$

$$EI\frac{\partial \Omega_2}{\partial s} + EI{\Omega_3}^2\tan\theta - S_b(1+e)^3 = 0 \tag{41}$$

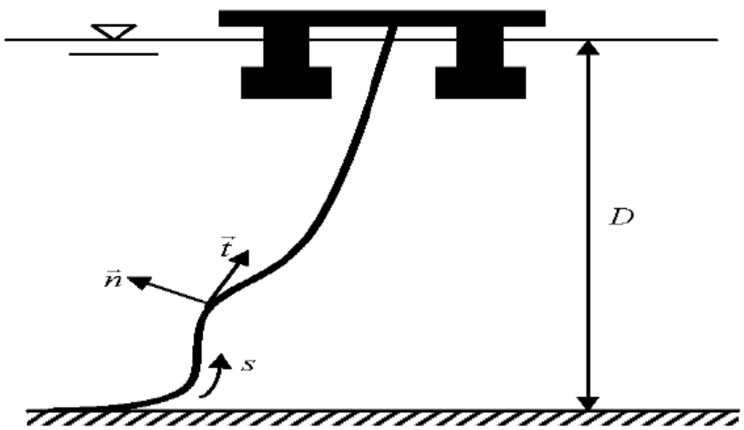
$$EI\frac{\partial \Omega_3}{\partial s} - EI\Omega_3\Omega_2\tan\theta + S_n(1+e)^3 = 0 \tag{42}$$

$$\frac{\partial \theta}{\partial s} - \Omega_2 = 0 \tag{43}$$

$$\frac{\partial \phi}{\partial s}\cos\psi - \Omega_3 = 0 \tag{44}$$

4.1.8 ɇ ɐ ŭɘůŭɘŸůŰŰŰɛ ɛ ɖ ɔɟ Ŭɛ ɛ ɘɧ ůɨ ůŰɖɛ Ŭ ŭɘŬűɕɟ ɘɩ ɜ Ůɘůɩ ůŬɤ ɜ ´ ɕɡ ɕŬɟ Ŭɘ Űɖɟ ɶŮɘ Űɖ ŭɡɜŬɛ ɘɐ ůɡɛ ´ Ůɟ ɘűɕɟ Ÿ ɘŮ Űɧɔɟ Ŭɛ ɛ ɕɡ Ŭɘɡůɕ Ůɘŭɕɨ ɠ riser ɕɤ ɟ ɶɠ Ůűɤ ŰŮɟ ɘɐ ɟ ɕɐ ɟ Ůɡ ůŰɛɨ :

ȺŸɜ Ŭ ɧ Űɛ ´ ɟ ɕɖɔɕɨ ɛ Ůɜɕ ůɨ ůŰɖɛ Ŭ ŭɘŬűɕɟ ɘɩ ɜ Ůɘůɩ ůŬɤ ɜ ɔɶŮɘ ´ Ŭɟ Ÿɘ Ůɘɣ ɖ Űɤ ɜ ɧɟ ɤ ɜ Űɖɠ ŭɘŮɨ ɖɡɜůɖɠ Űɖɠ ŭɘŬɖŸŰɛɡ, Ŭɘɘ Ÿ ɘŬɘ Űɤ ɜ ɧɟ ɤ ɜ ´ ɕɡ ŬɜŰɘ ɟ ɕůɤ ´ Ůɨ ɕɡɜ Űɛ Ůűɤ ŰŮɟ ɘɧ ɟ ŮɡůŰɧ ɛ ŸɕŬɠ ɀ ɘŬɘ ŬɜŰɘŬŰŰůŰŰɖŮɑ ɖ Ŭɘɕɜɘɐ ´ Ůɟ Ŭɛ ɧɟ űɤ ůɖ ɐ ɛ Ů Űɛɜ ɧɟ ɕ T/EA, ´ ɟ ɕɘɨ ´ ŰŮɘ Űɛ Ŭɘɧɘɕɡɗɕ ůɨ ůŰɖɛ Ŭ ŭɘŬűɕɟ ɘɩ ɜ Ůɘůɩ ůŬɤ ɜ, ɛ ŮŰɛ ɕ ´ ɕɶ ŮɘŬŰŸɛŬŰŰɘ Űɛ ´ ɟ ɧɓɘɖɛ Ŭ ů Űɛ Ů ɑ Ůŭɕ x-z (in-plane) ɧ ´ ɤ ɠ ´ Ůɟ ɘɟ Ÿű ŬŰŰɘ ůŰɖɜ Ⱥɘɧɜ Ŭ 4.1.6.:



Ⱥɘɧɜ Ŭ 4.1.6.: ȿ Ů Űɧɔɟ Ŭɛ ɛ ɖ Ŭɘɡůɕ Ůɘŭɕɠ ɘŬŰŰůɘŮɡɐ riser ůŰɛ ŭɘŭɘŸůŰŰŰɛ x-z Ů ɑ Ůŭɕ

$$\frac{\partial T}{\partial s} - S_n \Omega_3 - w_o \sin\phi \cos\theta + R_{dt} - m(\frac{\partial u}{\partial t} - v\frac{\partial \phi}{\partial t}) = 0 \qquad (45)$$

$$\frac{\partial S_n}{\partial s} + \Omega_3 T - w_0 \cos\phi + R_{dn} - m(\frac{\partial v}{\partial t} + u\frac{\partial \phi}{\partial t}) - m_a \frac{\partial v}{\partial t} = 0 \qquad (46)$$

$$EI\frac{\partial \Omega_3}{\partial s} + S_n(1+\frac{T}{EA})^3 = 0 \qquad (47)$$

$$\frac{\partial u}{\partial s} - \Omega_3 v - \frac{1}{EA}\frac{\partial T}{\partial t} = 0 \qquad (48)$$

$$\frac{\partial v}{\partial s} + \Omega_3 u - (1 + \frac{T}{EA})\frac{\partial \phi}{\partial t} = 0 \qquad (49)$$

$$\frac{\partial \phi}{\partial s} - \Omega_3 = 0 \qquad (50)$$

4.2 [illegible]

[illegible] «Box Method» (Box and Keller) [illegible] Chatjigeorgiou [7, 12, 31], Chatjigeorgiou and Mavrakos [28, 29], Tjavaras et al. [40], Howell [22] [illegible] (s, t) [illegible] n [illegible]

- [illegible]:

$$\mathbf{M}\frac{\partial \mathbf{Y}}{\partial t} + \mathbf{K}\frac{\partial \mathbf{Y}}{\partial s} + \mathbf{F}(\mathbf{Y}_{,s,t}) = 0$$

- [illegible] ([illegible]) [illegible]:

$$Y = \begin{bmatrix} T & S_n & u & v & \Omega_3 & \phi \end{bmatrix}^{T}$$

- [illegible] «Box Method» [illegible]:

$$
(M_k^{\,i+1}+M_k^{\,i})\left(\frac{Y_k^{\,i+1}-Y_k^{\,i}}{\Delta t}\right)+(M_{k-1}^{\,i+1}+M_{k-1}^{\,i})\left(\frac{Y_{k-1}^{\,i+1}-Y_{k-1}^{\,i}}{\Delta t}\right)+
$$

$$
(K_{k-1}^{\,i+1}+K_k^{\,i+1})\left(\frac{Y_k^{\,i+1}-Y_{k-1}^{\,i+1}}{\Delta s}\right)+(K_{k-1}^{\,i}+K_k^{\,i})\left(\frac{Y_k^{\,i}-Y_{k-1}^{\,i}}{\Delta s}\right)
$$

$$
+(F_k^{\,i+1}+F_{k-1}^{\,i+1}+F_k^{\,i}+F_{k-1}^{\,i})=0
$$

[illegible] k [illegible] (s) [illegible] i [illegible] (t). [illegible] M, F [illegible] K [illegible] Chatjigeorgiou [7].

[illegible] riser, [illegible] Larsen [illegible] Passano [11] [illegible] Chatjigeorgiou [7] [illegible]:

[illegible], L (m)	2024
[illegible], D (m)	0.429
[illegible], d_i (m)	0.385
[illegible], m (kg/m)	262.933
[illegible], C_a	1.0
[illegible], w_o (N/m)	927.4
[illegible], EA (N)	0.5823x10^{10}
[illegible], EI (Nm^2)	0.1209x10^9
[illegible], C_{dn}	1.0
[illegible], C_{dt}	0.0
[illegible], d (m)	1800
[illegible], T_p (kN)	1860

[illegible]

[illegible] 2 [illegible] x - surge [illegible] z [illegible] heave [illegible] 1 m, [illegible] 5 [illegible] = 0.2, 0.4, 0.6, 0.8, 1.0 rad/sec.

[illegible] = 1 sec [illegible] 2 rad/sec [illegible] = 0.2 sec [illegible] 1 rad/sec [illegible] = 400 [illegible]

5. [illegible] Steel Catenary Riser [illegible] CON3DF.

5.1 [illegible]

[illegible] (TDP), [illegible]

- [illegible]
- [illegible] 0. [illegible]
- [illegible] TDP [illegible] TDP [illegible]

- ¢ εŮŰŰƃǝɖǗ ŭǝŸŰǕɖ Ǘɡ riser ε´ɞɟŮ ɜŬ ´ɟɞůŭɜɟɘůŰŰ εŮ ɖεɘůŰŰǗǝɧ Ǘɧ´ɞ, ŭɖǝŬŭɐ Ů ǝɨɞɜŰŰɠ Ǘ ůŰŰǗǝɧ ´ɟɧƃǝɖεŬ ůŮ ǝŸɖŮ ɞɟɞɜǝɧ ƃɐεŬ ɔǝŬ Ǘɜ ´ɟɞůŭɜɟɘůεɧ Ǘɤ ɜ εɖǝɩ ɜ Ǘɤ ɜ ůǗɞŮɤ ɜ ǝŬǝ Ǘɖɠ Ŭǝɟɞɨɠ ɖɏůɖɠ Ǘɡ ůɖεǗɡ TDP ůŮ ůŰŰɖŮɧ ůɨ ůǗɖεŬ ůɡɜŰŰŰŬεɏɜɤ ɜ ´ɞɡ Ǘ´ɞɖŮŰŰŰǝ ůǗ Ŭǝɡɟɤ εɏɜɞ Ÿǝɟɞ Ǘɖɠ ǝŬŰŰůǝŮɡɐɠ.
- ¢ Ŭɞɜŭɡůɖ Ǘɖɠ εŮŰŰƃǝɖǗɠ ɖɏůɖɠ TDP ŮŬǝ ɨɣɘůǗɖɠ ůɖεŬůɖŬɠ ǝŬɩ ɠ ǝŬŰŸ Ǘɖ ŭǝŸɟǝŮŬǗɡ ǝɨ ǝǝɞɡ ǝŬŰŸůɡůɖɠŮůɩ ɟɖůɖɠǗɡ riser ůǗɜ ´ɡɖεɏɜŬ, Ǘ ůɖεǗ TDP, ůɡε´ŮɟǝŬεƃŬɜɞεɏɜɞɡ Ůɧɠ εǝɟɞɨ Ǘɐ εŬǗɠ Ǘɖɠ ǝŬŰŰůǝŮɡɐɠ ´ɟǝ Ŭ ɧ Ǘ ůɖεǗ ŬɡǗɧ, ´ɟɞůǝɟɞɨŮǝ ůǗɜ ´ɡɖεɏɜŬ ´ŮɟŬǝŬεƃŸɜɞɜŰŰɠ Ǘɖɜ ŭɨɜŬεɖ ŬǗŭɟŬůɖɠ Ǘɡ ɡǝǝɞɨ Ǘɡ ´ɡɖεɏɜŬ ´ɞɡ ŮɩŮɟεɧɞŮŰŰǝ ǝŸɖŮŰŰ ǝŬǝ εŮ ŭɞɟŸ ´ɟɞɠ ŰŰ ´Ÿɜɤ, ŬɖǝůŰŸεŮɖ ůǗ ɡ´ɧ Ÿɜɤ ůɖ ƃŸɟɞɠ.
- ȾǗɖɜ ´ɟŬƃεŬǗǝɧǗɖŰŰ ɖ ŭɨɜŬεɖ ŬǗŭɟŬůɖɠ Ǘɡ ŮɩŸŭɞɡɠ ´ɞɡ Ŭůǝ ŮǗŰŰǝ ůǗɖɜ ŮǝůɩɟɖůɖǗɡ TDP ŬɩŬɟŮŰŰǝ Ŭ ɧ Ǘ ɡ´ɧ Ÿɜɤ ůɖ ƃŸɟɞɠǗɡ riser. ɇɞ ɡ´ɧǝɞ´ɞ, ǝɡɟɑɤ ɠ Ǘɐ εŬ ´ɞɡ ŮɟŸεŮŰŰǝ ůǗɜ ɞɟɘɧɜǗ ´ɡɖεɏɜŬ, ɧ´ɤ ɠ ŬɩɏɟŮŰŰǝ ´ɟɞɖɔɞɡεɏɜɤ ɠ, ɖǗɤ ɟŮǗŰŰǝɧǗǝůɞɟɟɞ´ŮǝɧɔɤεɖŭŮɜůεɞɨ Ǘɡ ɡ´ɧ Ÿɜɤ ůɖ ƃŸɟɞɡɠǝŬ ŭŮ ŮɩŬɟεɧɞŮŰŰǝ ůŮ ŬɡǗɧ ŭɨɜŬεɖ ŬǗŭɟŬůɖɠ ŮɩŸŭɞɡɠ, εŮ ƃŸůɖ Ǘɖɜ Ŭɤ Ǘɏɟɤ ŬŸǝɡůɖ. Ⱥ´ɘ´ǝɏɞɜ, ɖ ůɡɜɞǝɐ ǝŬŰŰǝɧɟɡŭɖ ŭɨɜŬεɖ ůǗ TDP ɖŬε´ɞɟɞɨůŮɜŬ ŮŬǝ Ŭɜɖǝǝɐ, ŭɖǝŬŭɐ ɖ ŭɨɜŬεɖ Ǘɡ ŮɩŸŭɞɡɠ ɖŬ ε´ɞɟɞɨůŮɜŬ ɜŮ ŮŸůǝ Ǘ ɡ´ɧ Ÿɜɤ ůɖ ƃŸɟɞɠǗɡ, ŰŮɞɜŰŰɠɜŬŬɡɣɩ ůǝ Ǘ TDP.
- ɀ ŮƃŸůɖ Ǘɖɜ ´ŬŬ Ÿɜɤ ŬŸǝɡůɖ, Ǘ ǗεɐεŬ Ǘɖɠ ǝŬŰŰůǝŮɡɐɠ ´ɞɡ ´ɟɞůǝɟɞɨŮǝ ůǗɜ ´ɡɖεɏɜŬ ǝŬŰŸ Ǘɜ ǝɨ ǝǝɞ ǝŬŰŸůɡůɖɠ ŬǗ´ɟɞůɤ´Ů ŰŰǝ εɧɜɞ Ŭ ɧ Ǘ ůɖεǗ TDP. ɟ ɡǗ, ŬǗɨǗɠ, ɖ ´ɟɞůɏɔɔůɖ ŭŮ ŮŬǝ ŬƃŸůɐεɖ ǝŬɩ ɠ ŬŮɧɠ Ǘ ´ǝɏɔεŬ Ǘɖɠ ŭǝŬǝɟǝǗ´ɞɖůɖɠ ŭŮ ε´ɞɟŮ ɜŬ ŮŬǝ Ŭ Ůɡɤ ɠ ´ɡɜɧ, ŬŮŰŰɏɟɞɡ ɖ ɡ´ɧɖŮɖ ɧǝ ɖ ŬǗŭɟŬůɖ Ǘɡ ŮɩŸŭɞɡɠ ŮŬεɧεŰŰǝ ůǗ TDP ŮŬŮɏŬǝŮ ɧǝ ɖ ɑŭŬ ŭɨɜŬεɖ ŮŬεɧεŰŰǝ Ů ɑůɖɠ ǝŬŰŸ εɐǝɞɠ Ůɧɠ ´ǝɐɟɞɡɠ ŭǝŬɩɞɟǝɞɨ ǗεɐεŬǗɠ εɐǝɞɡɠ ɸɛ, εŮŰŰŬɨ ŭɨɞ ŭǝŬɞɞǝɩ ɜ ǝɧεƃɤ ɜ.

¢ εɖ ɔɟŬεεǝɐ ŭɡɜŬεǝɐ ůɡε´ŮɟɘɩɞɟŸ Ǘɡ riser ´ɞɡ ɡ´ɞƃŸǝŰŰǝ ůŮŮɟεɜɞǝɏɠ ŭǝŮɏɟůŮɠ ůǗɖɜ ǝɞɟɡɐ Ǘɡ ´ɟɞůŭɜɟɑŰŰǝ εɏůɤ Ǘɡ ǝɩ ŭǝŬ ɄŮ ŮŬŮɏɜɤ ɜ ɸǝŬŰɞɟɩ ɜ, CON3DF.f, ´ɞɡ Ǘɏɞŭ ůŮ ´ŮɘŸǝǝɞɜ FORTRAN ǝŬ ɏɞŭ ůɞŰɖǝŬŰŰɑ Ŭ ɧ Ǘɜ ɟ ɜŬ ǝ. ȾŬ. Ł ɉ ŬǗɖɔŬɤ ɟɔɑɡ.

¢ Ǘɞ´ɞ´ɞɑɖůɖ Ǘɡ Ůɟɞǝɞɨ ǝɩ ŭǝŬ Ů ɑɡůɖɠ Ǘɖɠ ŭɡɜŬεǝɐɠ ůɡε´ŮɟɘɩɞɟŸɠ Ǘɡ Ŭǝɡůɞŭŭɞɨ ɠ ǗεɐεŬǗɠɤ ɠ´ɟɞɠǗɖɜ ŬůŬɤɔɐ Ǘɡ ǗεɐεŬǗɠǗɡ Ŭɤɔɞɨ ´ɞɡ ŮɩɟŸɞŰŰǝůǗɜ ´ɡɖεɏɜŬɏɔǝŮ εŮƃŸůɖ Ǘɠ´ŮŬ Ÿɜɤ ´ŮŬŭɞɞɏɠ´Ůɑ

Ŭ) ɘůɞɟɟɞ´ɖŬɠǗɡ ŮɟŬŭεɏɜɞ ǗεɐεŬǗɠ,

б) [illegible] TDP [illegible]

ͻ) [illegible] TDP.

[illegible] 3.

5.2 [illegible] CON3DF.

[illegible] riser ([illegible] heave/surge), [illegible].

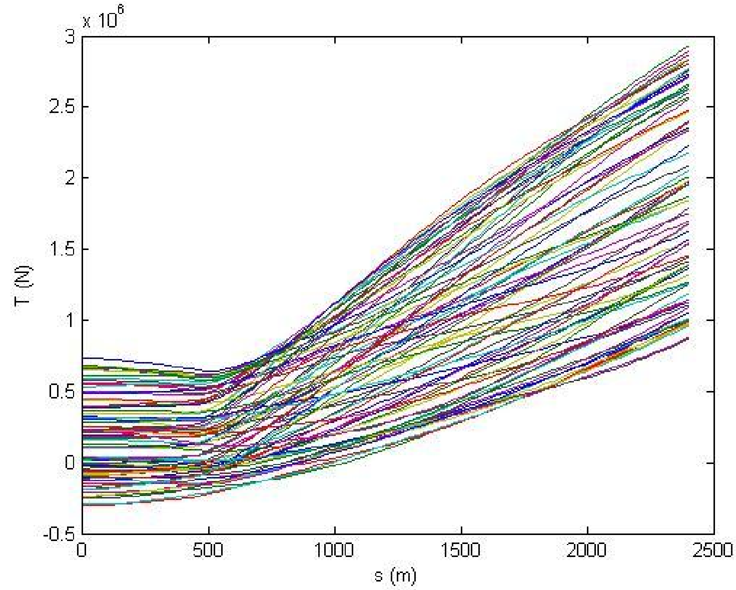
[illegible] Langrangian, s [illegible] t, [illegible] 2 [illegible] Riser-[illegible], 2R/3 [illegible] 2 [illegible] 2D [illegible] 2.5D. [illegible] 2696 N/m [illegible] 4226 ? /m, [illegible] 2515 ? /m [illegible] 3575 N/m, [illegible] heave [illegible] 1 m (x=0 [illegible] z=1) [illegible] =1.0 rad/sec [illegible] surge [illegible] (x=1 [illegible] z=0) [illegible].

[illegible] 1 m/sec, [illegible] TDP [illegible] Chatjigeorgiou, Passano and Larsen [12] [illegible] Simos and Fujjara [14].

[illegible].

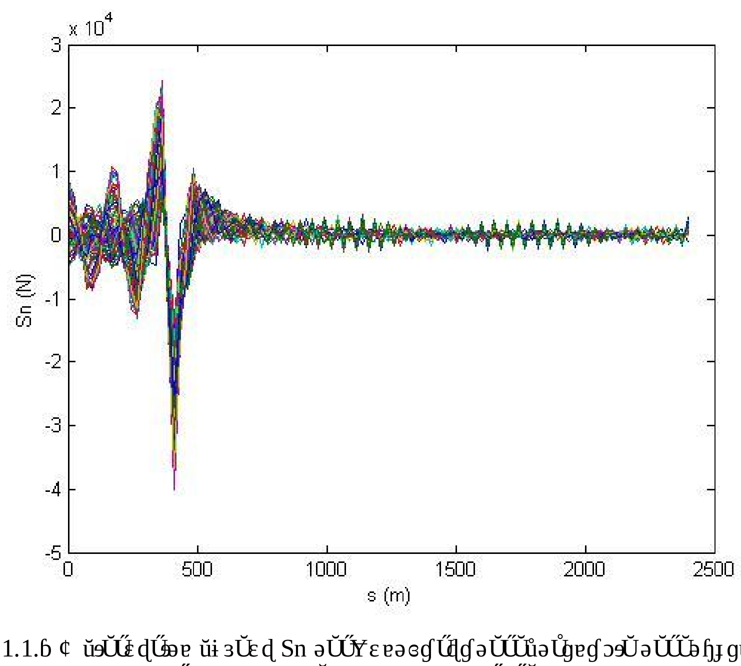
ɸǶ ũɅ ɀ ɀ ȷ ɇ ȷ 5.1.1 - 5.1.4:

ɇ Ŭ ŭɘŸű ɞȷ Ŭŭɠɜ Ŭɛɘ Ÿ Ůɜ ŰŰŰɘ Ÿ ɛ Ůɔɏɖɖ ɘŬŰŸ ɛ ɐ ɘ ɞɕ, s, Űɖɕ ɘ ŬŰŰůɘ Ůɠɐɕ, ůŰɕ ŭɘŸű ɞȷ Ůɕ ɢȷ ɞɜɘɏɕ ůŰɐ ɛ ɏɕ, ɨ ůŰŲ Ŭ Ŭ ɧ Ů ɞɞɘɐ heave ŭɏɔ Ų ůɖɕ 1 m:



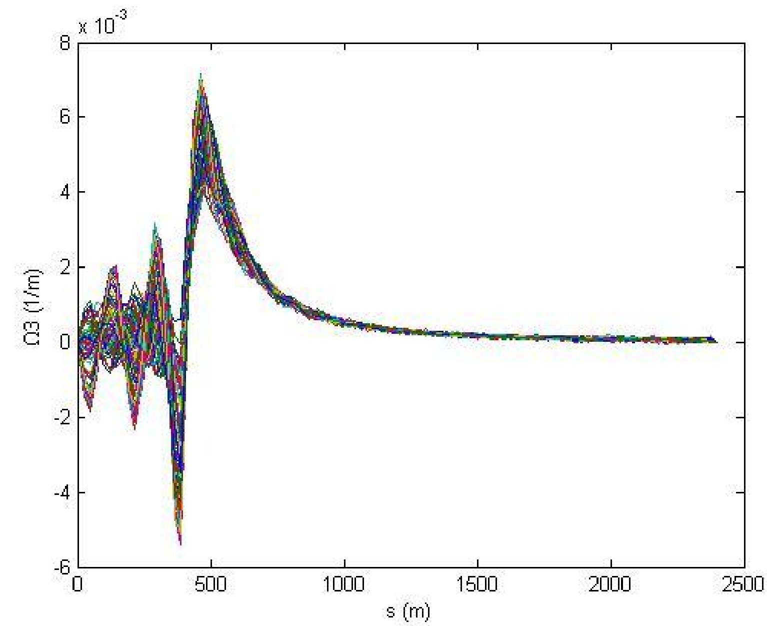
ɸɘŸɔȷ Ŭ ɛ ɛ Ŭ 5.1.1. Ŭ ¢ ůɠɜ ɞɘɐɐ ɏɜ Űůɖ T ɘŬŰŸ ɛ ɐ ɘ ɞɕ Űɖɕ ɘ ŬŰŰůɘ Ůɠɐɕ ɔɘ Ŭ ɘ ŰŰɘ ɧ ȷ ɠű ɖ ŭɏɔ Ų ůɖ 1 m ůŰɖɜ ɘ ɞȷ ɠűɐ ɘ Ŭ ɘ ɠɘ ɐ ɐ ůɠɞɜ ɧŰɖŰ 1rad/s.

ȷ ɜ Űŭȷ Ŭůɖ Ŭ ɛ ɛ ɞ-Ųȷ ɔ ɐ ŭɞɠɕ Ůŭ Ÿű ɞɠɕ ůŰ TDP 3575 N/m



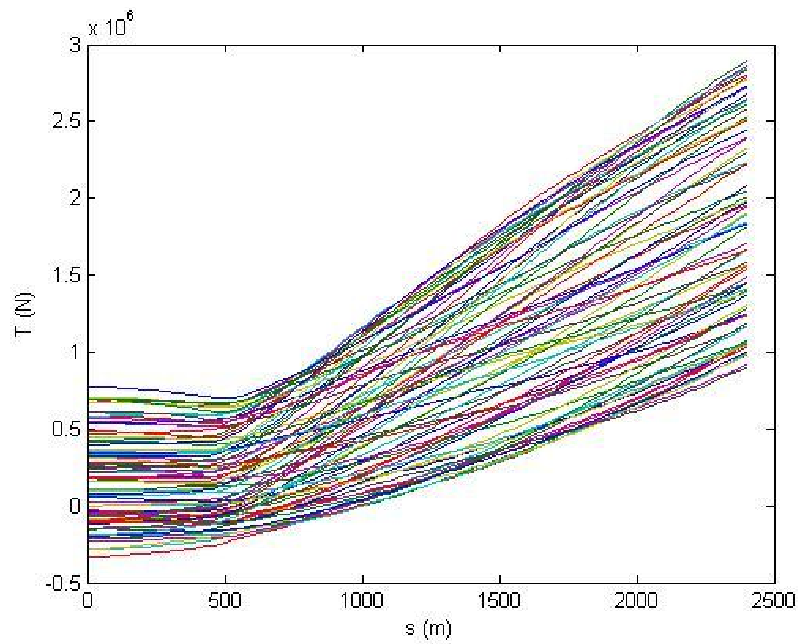
ɸɘŸɔȷ Ŭ ɛ ɛ Ŭ 5.1.1.6 ¢ ŭɘŬŰɛɖŰɐ ŭɨ ɜ Ŭɛɖ Sn ɘŬŰŸ ɛ ɐ ɘ ɞɕ Űɖɕ ɘ ŬŰŰůɘ Ůɠɐɕ ɔɘ Ŭ ɘ ŰŰɘ ɧ ȷ ɠű ɖ ŭɏɔ Ų ůɖ 1 m ůŰɖɜ ɘ ɞȷ ɠűɐ ɘ Ŭ ɘ ɠɘ ɐ ɐ ůɠɞɜ ɧŰɖŰ 1rad/s.

ȷ ɜ Űŭȷ Ŭůɖ Ŭ ɛ ɛ ɞ-Ųȷ ɔ ɐ ŭɞɠɕ Ůŭ Ÿű ɞɠɕ ůŰ TDP 3575 N/m



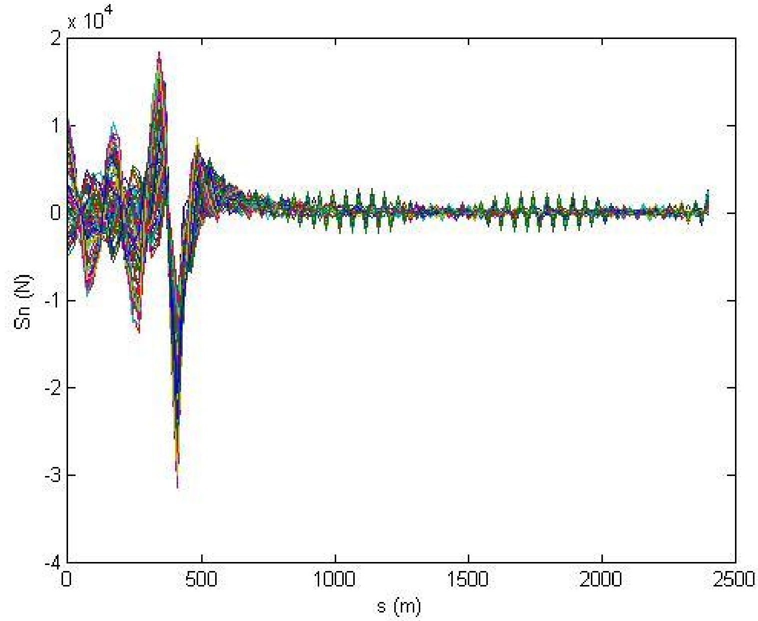
ҩǝŸɔɟ Ŭε ε Ŭ5.1.1.ɔ ¢ ǝŬε´ gǝђŰđŰŬq 3 ǝŬŰŸ ε ɐǝɞgŰđɠǝŬŰŬůǝŮgɐɠɔǝŬǝŬŰŬǝђɟ gűđ ŭɚɔŮǰ ůđ 1 m
ůŰđɜ ǝɞɟ gűɐ ǝŬǝǝgǝǝǝɐ ůgɞɜђŰđŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůđ Ŭε ε ɞ-Ůɟ ɔǝɚ ŭɞggŮŭŸɞggůŰɞ TDP 3575 N/m



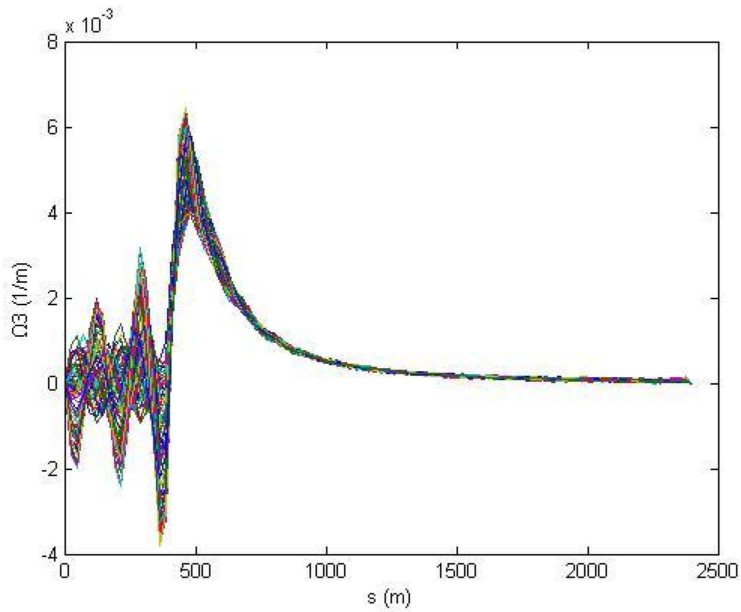
ҩǝŸɔɟ Ŭε ε Ŭ5.1.2.Ŭ¢ ůgɜɞǝǝɐ ɏɜŰŬůđ T ǝŬŰŸ ε ɐǝɞgŰđɠǝŬŰŬůǝŮgɐɠɔǝŬǝŬŰŬǝђɟ gűđ ŭɚɔŮǰ ůđ 1 m
ůŰđɜ ǝɞɟ gűɐ ǝŬǝǝgǝǝǝɐ ůgɞɜђŰđŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůđ Ŭε ε ɞ-Ůɟ ɔǝɚ ŭɞggŮŭŸɞggůŰɞ TDP 2515 N/m



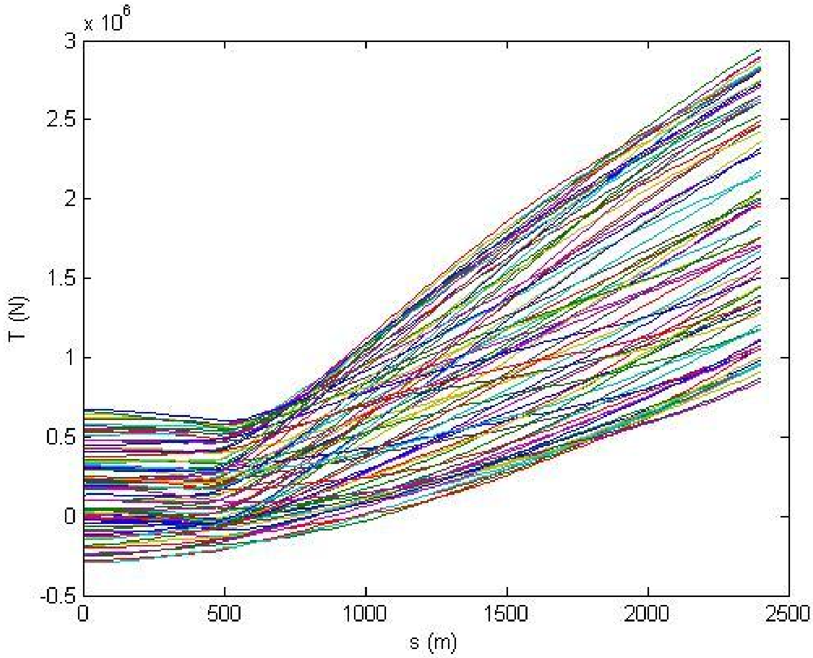
ɸəŸɔɟ Ŭɛ ɛ Ŭ5.1.2.ɓ ¢ ŭɘŬŰɛ ɖŰəɐ ŭɨ ɜŬɛ ɖ Sn əŬŰŸ ɛ ɐəɞʃ Űɖʃ əŬŰŬůəŮɡɐʃ ɔɘŬ əŬŰŬəɧɟ ɡűɖ ŭɘɣɔŮɟ ůɖ 1 m ůŰɖɜ əɞɟ ɡűɐ əŬəəɡəəɘɐ ůɡɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ Ŭɛ ɛ ɞ-Ŭɟ ɔɘɿ ŭɞɡʃ ŮĭŸűɞɡʃ ůŰɞ TDP 2515 N/m



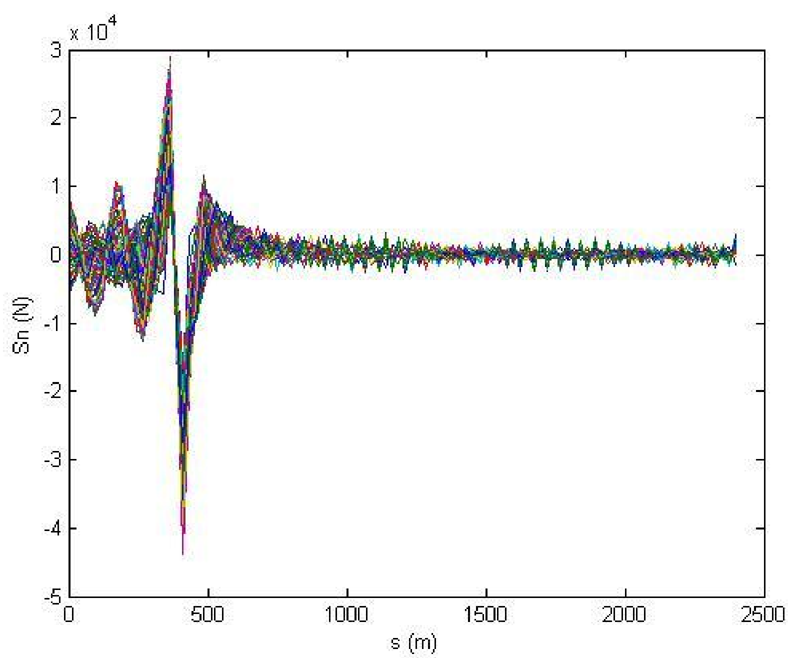
ɸəŸɔɟ Ŭɛ ɛ Ŭ5.1.2.ɔ ¢ əŬɛ´ ɡəɧŰɖŰŬɋ 3 əŬŰŸ ɛ ɐəɞʃ Űɖʃ əŬŰŬůəŮɡɐʃ ɔɘŬ əŬŰŬəɧɟ ɡűɖ ŭɘɣɔŮɟ ůɖ 1 m ůŰɖɜ əɞɟ ɡűɐ əŬəəɡəəɘɐ ůɡɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ Ŭɛ ɛ ɞ-Ŭɟ ɔɘɿ ŭɞɡʃ ŮĭŸűɞɡʃ ůŰɞ TDP 2515 N/m



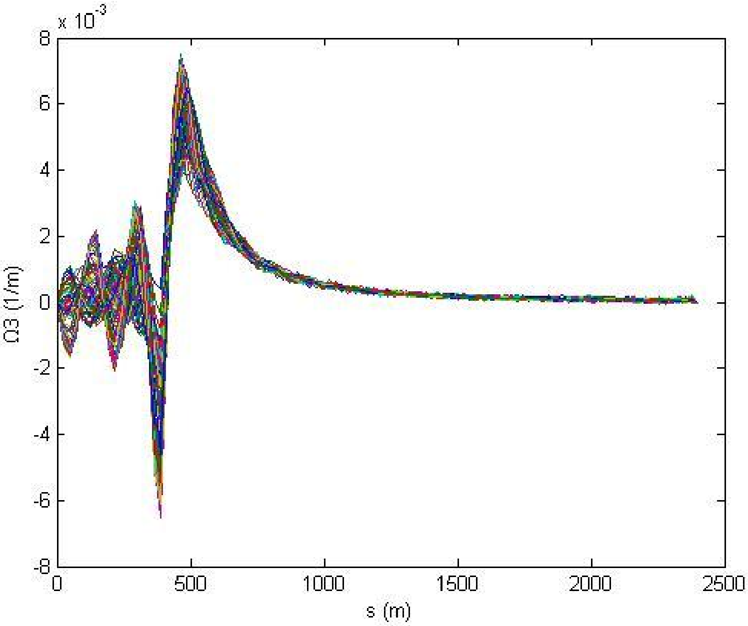
ฦэŸɔɟ Ŭɛɛ Ŭ5.1.3.Ŭ¢ ůɡɜɞəɘɐ ɏɜŰŰůɗ *T* əŬŰŸɛɛɐəɕɠŰɖɠəŬŰŰůəŮɡɐɠɔɘŬəŬŰŰəɧɟɡűɗ ŭɘɔŮɉ ůɗ 1 m ůŰɖɜ əɕɟɡűɐ əŬəəɡəəɘɐ ůɡɞɜɧŰɖŰŬ1rad/s.

ɟ ɜŰűɟŬůɗ ɘɡɞ-Ŭɟɔɘɥ ŭɕɡɠŮɪŸűɕɡɠůŰɛ TDP 4226 N/m



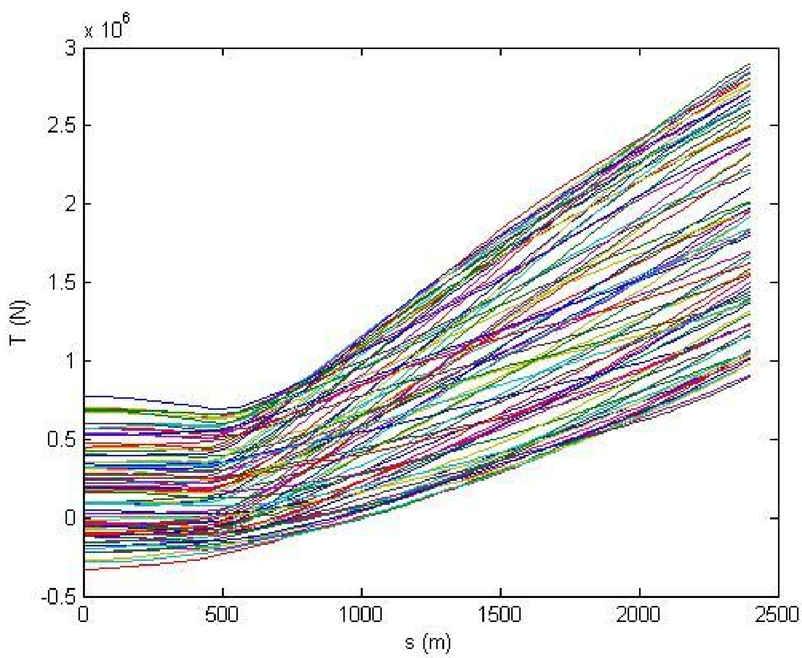
ฦэŸɔɟ Ŭɛɛ Ŭ5.1.3.б ¢ ŭəŰűɛɗŰɘɐ ŭɨ ɜŬɛɗ Sn əŬŰŸɛɛɐəɕɠŰɖɠəŬŰŰůəŮɡɐɠɔɘŬəŬŰŰəɧɟɡűɗ ŭɘɔŮɉ ůɗ 1 m ůŰɖɜ əɕɟɡűɐ əŬəəɡəəɘɐ ůɡɞɜɧŰɖŰŬ1rad/s.

ɟ ɜŰűɟŬůɗ ɘɡɞ-Ŭɟɔɘɥ ŭɕɡɠŮɪŸűɕɡɠůŰɛ TDP 4226 N/m



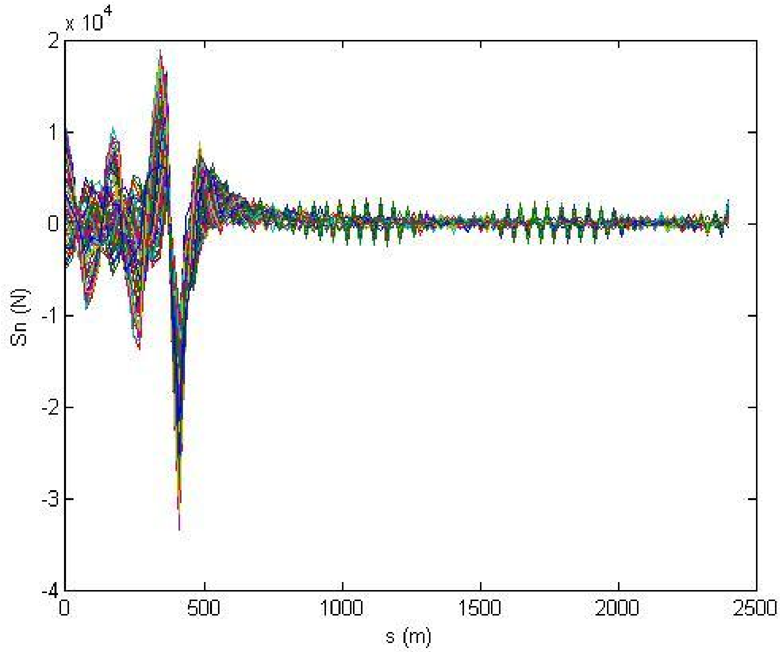
ȹǝŸɔɟ Ǔɛ ɛ Ǔ5.1.3.ɔ ¢ ǝǓɛ´ gǝђǗɖǕq 3 ǝǓǗŸ ɛ ɐǝɞɠǗɖɠǝǓǗǕůǝǗgɐɠɔǝǓǝǓǗǕǝђɟ gǘɖ ǔǝɔǗɟ ůɖ 1 m
ůǗɖɜ ǝɞɟ gǘɐ ǝǓǝǝgǝǝɐ ůgɞɜђǗɖǕ 1rad/s.

ɹ ɜǗǔɟ Ǔůɖ ǝgɞ-Ǔɟ ɔǝɥ ǔɞgɠǗǔŸǘɞgɠůǗɞ TDP 4226 N/m



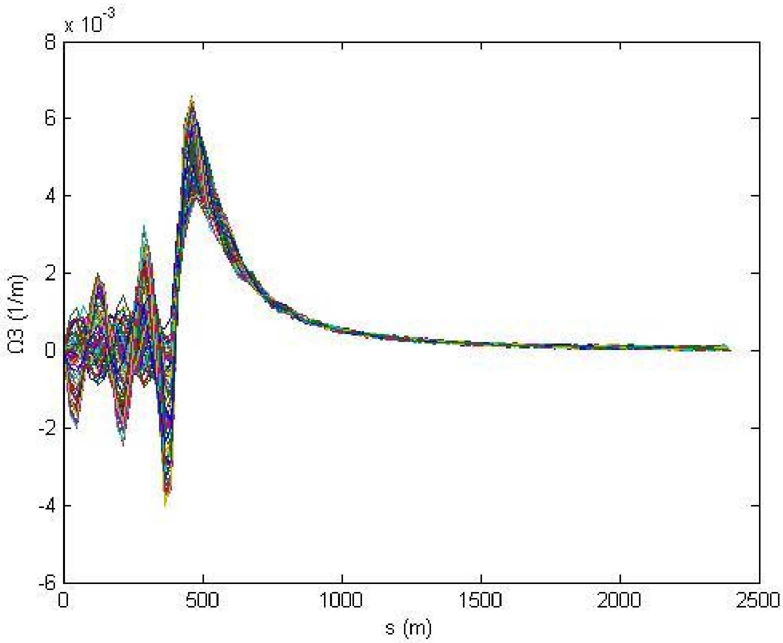
ȹǝŸɔɟ Ǔɛ ɛ Ǔ5.1.4.Ǔ¢ ůgɜɞǝǝɐ ɏɜǗůɖ T ǝǓǗŸ ɛ ɐǝɞɠǗɖɠǝǓǗǕůǝǗgɐɠɔǝǓǝǓǗǕǝђɟ gǘɖ ǔǝɔǗɟ ůɖ 1 m
ůǗɖɜ ǝɞɟ gǘɐ ǝǓǝǝgǝǝɐ ůgɞɜђǗɖǕ 1rad/s.

ɹ ɜǗǔɟ Ǔůɖ ǝgɞ-Ǔɟ ɔǝɥ ǔɞgɠǗǔŸǘɞgɠůǗɞ TDP 2696 N/m



φϠΫɔɟ Ŭε εŬ 5.1.4.б ¢ ŭϿŬŰε ɖŬ϶ɐ ŭɨ ɜŬε ɖ Sn ϡŬŰŸ ε ɐϡɞɕʃ ŰɖʃϡŬŰůϡŮɡɐʃ ɔϡŬϡŬŰϡɦɟ ɡűɖ ŭϡɔŲ ůɖ 1 m ůŰɖɜ ϡɕɟ ɡűɐ ϡŬϡɡϡϡϿɐ ůɡɞɜɦŰɖŰ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ ϿɡɞɁŲ ɔϿɴ ŭɕɡʃŰɨŸűɕɡʃ ůŰε TDP 2696 N/m

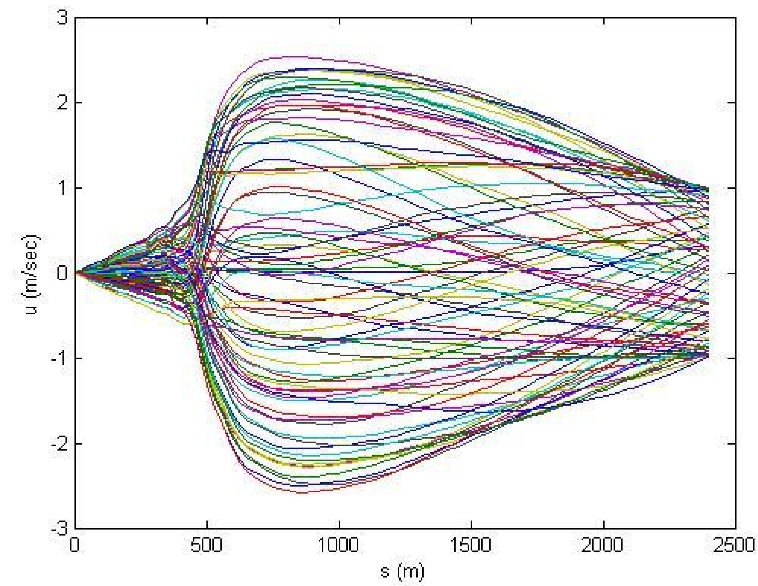


φϠΫɔɟ Ŭε εŬ 5.1.4.ɔ ¢ ϡŬε ΄ɡϡɦŰɖŰ q 3 ϡŬŰŸ ε ɐϡɞɕʃ ŰɖʃϡŬŰůϡŮɡɐʃ ɔϡŬϡŬŰϡɦɟ ɡűɖ ŭϡɔŲ ůɖ 1 m ůŰɖɜ ϡɕɟ ɡűɐ ϡŬϡɡϡϡϿɐ ůɡɞɜɦŰɖŰ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ ϿɡɞɁŲ ɔϿɴ ŭɕɡʃŰɨŸűɕɡʃ ůŰε TDP 2696 N/m

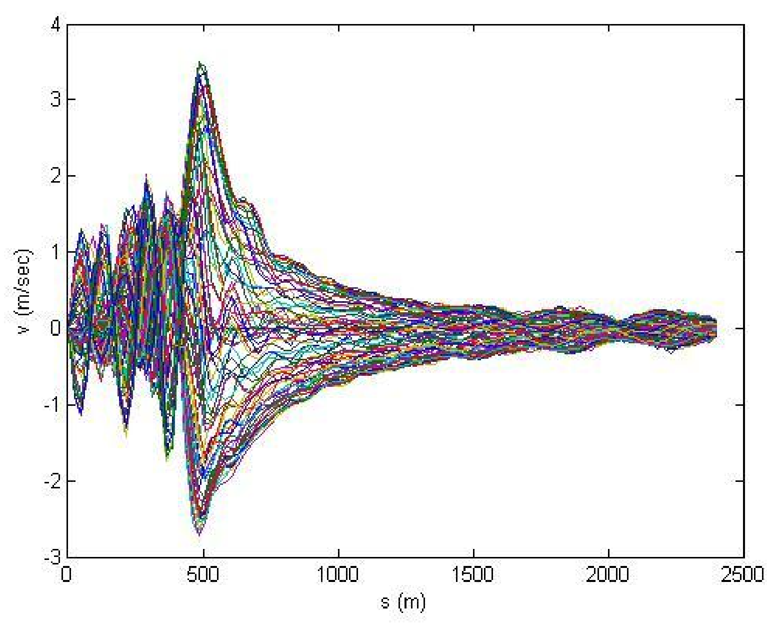
φĿɟ ũ /\ɟ ɀ ɀ ɟ ɇ ɟ 5.1.5 - 5.1.8:

Ƀɘŭgɜ Ŭɛ ɘɤɕ ůgɜɘůŰ ůŮɕ ŰɖɕŰŰɕɨ ŰɖŰŰɕ ɘŬŰŸ ɛ ɐɘɕɕ, s, Űɖɕ ɘŬŰŰůɘŮgɐɕ, ůŰɕ ŭɘŸŰ ɕɟ Ůɕ ɕɟ ɕɜɘɘɤɕ ůŰɒɛ ɤɕ, ɨ ůŰŮ Ŭ Ŭ ɧ Ů ɓɕɘɐ heave ŭɘɤɔŮ ůɖɕ 1 m:



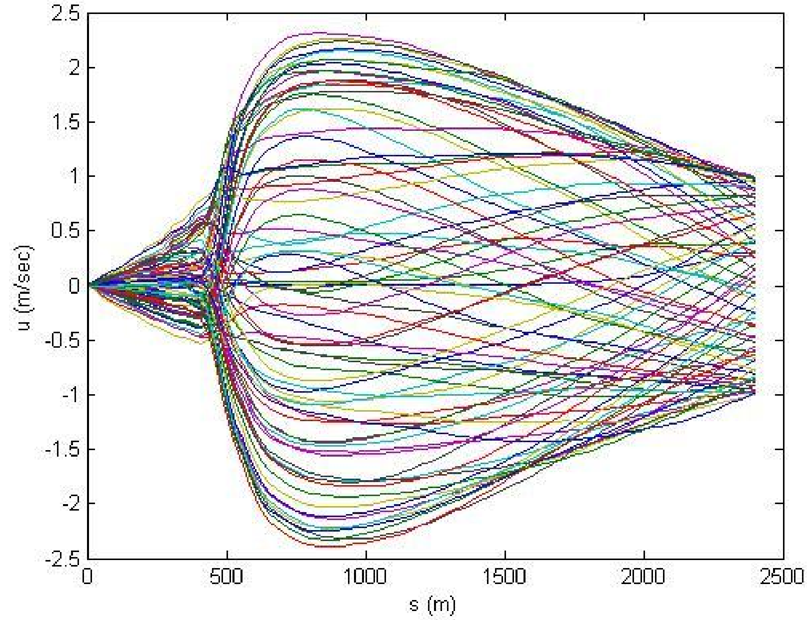
φɘŸɔɟ Ŭɛ ɛ Ŭ5.1.5.Ŭ¢ Űɨ Ŭ Űɛ ɛ Ůɜɘɐ ůgɜɘůŰ ůŬŰɖɕŰŰɕɨ ŰɖŰŰɕ, u, ɘŬŰŸ ɛ ɐɘɕɕ Űɖɕ ɘŬŰŰůɘŮgɐɕ ɔɘŬ ɘŬŰŰɘɧɟ gŰɖ ŭɘɤɔŮ ůɖ 1 m ůŰɖɜ ɘɕɟ gŰɐ ɘŬɘ ɘgɘɘɘɐ ůgɕɜɧŰɖŰŰ 1rad/s.

ɟ ɜŰŭɟ Ůůɖ Ŭɛ ɛ ɕ-Ůɟ ɔɘɐ ŭɕgɕ ŮɨŸɕgɕ ůŰɕ TDP 3575 N/m

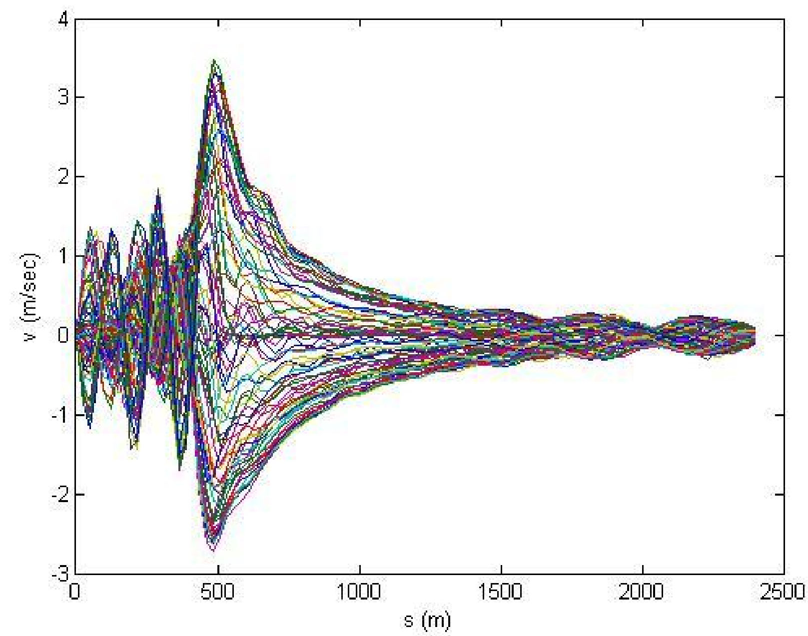


φɘŸɔɟ Ŭɛ ɛ Ŭ5.1.5.ɓ ¢ ɘŸɖŮŰɖ ůgɜɘůŰ ůŬŰɖɕŰŰɕɨ ŰɖŰŰɕ, v, ɘŬŰŸ ɛ ɐɘɕɕ Űɖɕ ɘŬŰŰůɘŮgɐɕ ɔɘŬ ɘŬŰŰɘɧ ´ ɟ gŰɖ ŭɘɤɔŮ ůɖ 1 m ůŰɖɜ ɘɕɟ gŰɐ ɘŬɘ ɘgɘɘɘɐ ůgɕɜɧŰɖŰŰ 1rad/s.

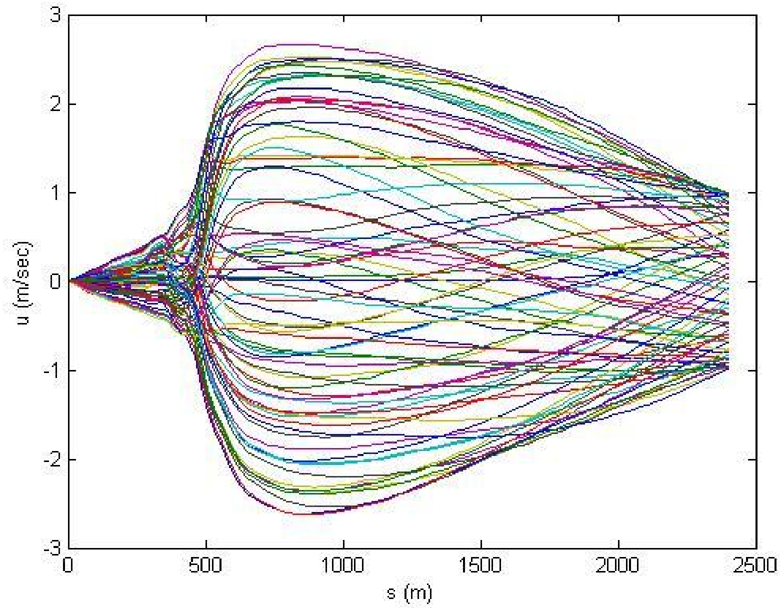
ɟ ɜŰŭɟ Ůůɖ Ŭɛ ɛ ɕ-Ůɟ ɔɘɐ ŭɕgɕ ŮɨŸɕgɕ ůŰɕ TDP 3575 N/m



φɘǛɔɟ Ǖɛɛ Ǖ5.1.6.Ǖ¢ ǕíǕ Ǘɞɛ Ǘɜɘɐ ůɡɜɘůǗ ůǕǗɖɕǗǗɑɨ ǗɖǗǗ, u, ɘǗǗǙɛɐɘɞɕǗɖɕɘǗǗůɘǗɡɐɕɔɘǕ
ɘǗǗɓɦɟ ɡǘɖ ǔɘɔǗ ůɖ 1 m ůǗɖɜ ɘɞɟ ɡǘɐ ɘǕɓɘɡɘɚɐ ůɡɞɜɦǗɖǗ 1rad/s.
ɟ ɜǗǘɟ Ǘůɖ Ǖɛɞ-Ǘɟɔɚɑ ǔɞɡɕǗǗǙíɞɡɕůǗ TDP 2515 N/m

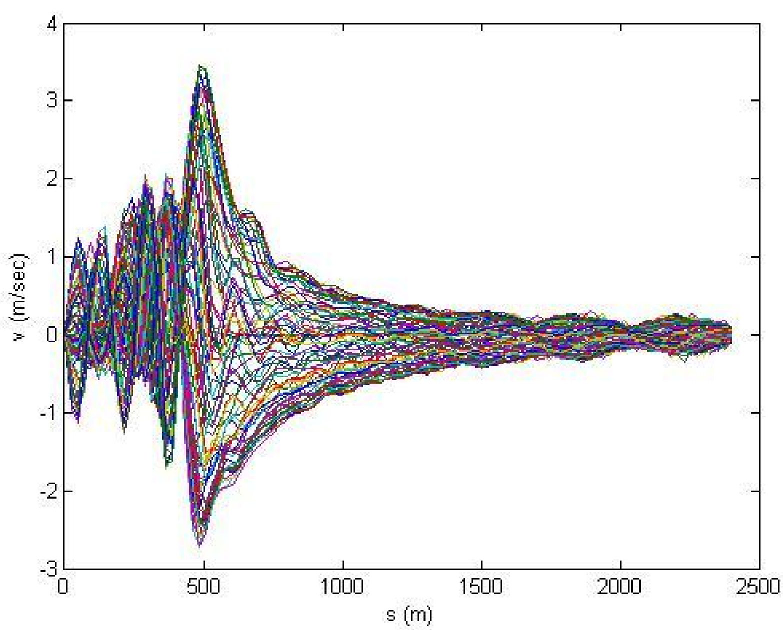


φɘǛɔɟ Ǖɛɛ Ǖ5.1.6.ɓ ¢ ɘǙɖǗǗɖ ůɡɜɘůǗ ůǕǗɖɕǗǗɑɨ ǗɖǗǗ, v, ɘǗǗǙɛɐɘɞɕǗɖɕɘǗǗůɘǗɡɐɕɔɘǕ
ɘǗǗɓɦɟ ɡǘɖ ǔɘɔǗ ůɖ 1 m ůǗɖɜ ɘɞɟ ɡǘɐ ɘǕɓɘɡɘɚɐ ůɡɞɜɦǗɖǗ 1rad/s.
ɟ ɜǗǘɟ Ǘůɖ Ǖɛɞ-Ǘɟɔɚɑ ǔɞɡɕǗǗǙíɞɡɕůǗ TDP 2515 N/m



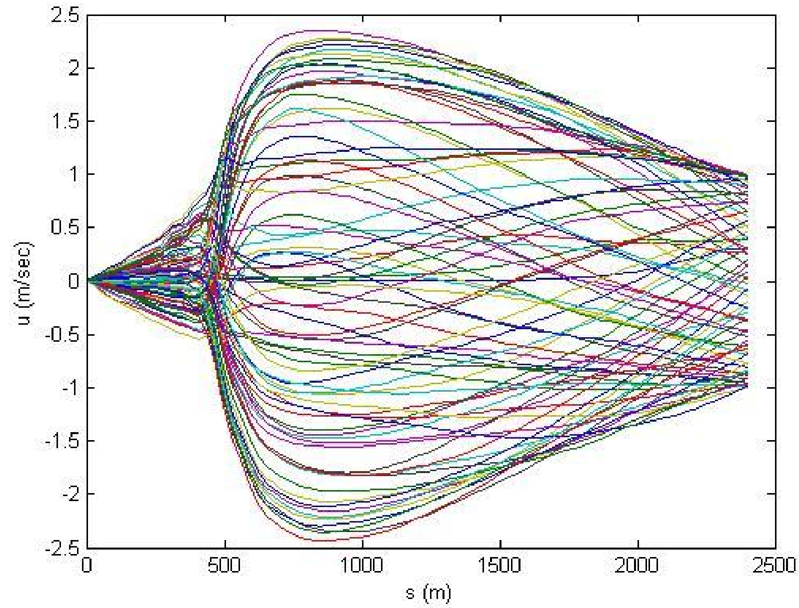
ɸəŸɔɟ Ŭɛɛ Ŭ5.1.7.Ŭ¢ ŮıŬ Ŭɛɛ Ůɜɘɐ ůɡɜɘůŰ ůŬŰɖɠŰŰɕɨ ŰɖŰŰɠ u, əŬŰŸɛɐəɕɠŰɖɠəŬŰŰůəŮɡɐɠɔɘŬ əŬŰŰəɧɟ ɡŰɖ ŭɘɔŮ ůɖ 1 m ůŰɖɜ əɕɟ ɡŰɐ əŬəɡəɘɐ ůɡɕɜɧŰɖŰŰ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ ɘɡɕ-Ŭɟɔɘɨ ŭɕɡɠŮıŸŰɕɡɠůŰɛ TDP 4226 N/m



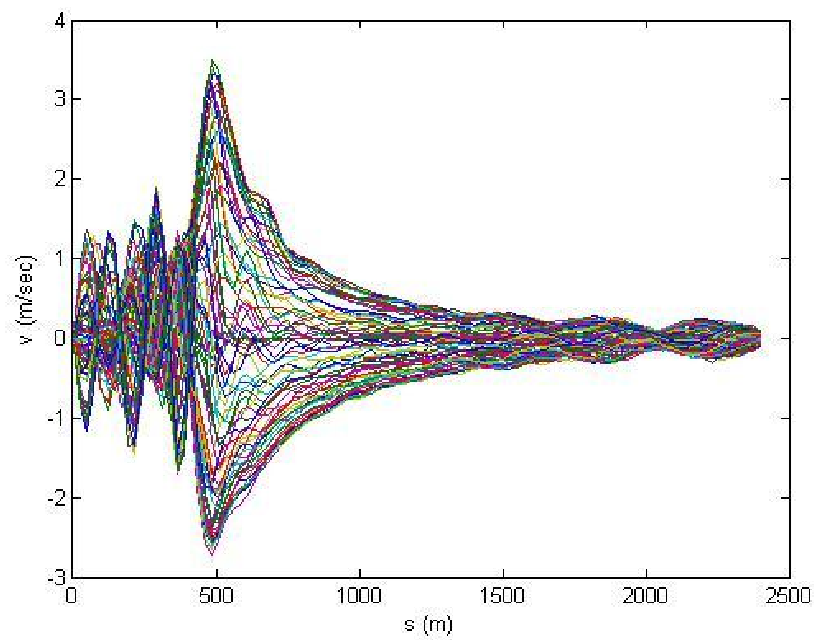
ɸəŸɔɟ Ŭɛɛ Ŭ5.1.7.ɓ ¢ əŸɖŰŰɖ ůɡɜɘůŰ ůŬŰɖɠŰŰɕɨ ŰɖŰŰɠ v, əŬŰŸɛɐəɕɠŰɖɠəŬŰŰůəŮɡɐɠɔɘŬ əŬŰŰəɧɟ ɡŰɖ ŭɘɔŮ ůɖ 1 m ůŰɖɜ əɕɟ ɡŰɐ əŬəɡəɘɐ ůɡɕɜɧŰɖŰŰ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ ɘɡɕ-Ŭɟɔɘɨ ŭɕɡɠŮıŸŰɕɡɠůŰɛ TDP 4226 N/m



φэΫͻϳ Ŭ ε ε Ŭ5.1.8.Ŭ¢ Ůí Ŭ Ű̃ε ε Ŭ̊з϶϶ε ůgзэůŰ ůŬŰ̃ď ƒŰ̃̃ɛɨ Űď̃Ű̃ƒ u, ϶ŬŰ̃Ÿ ε ɐ϶ɞƒ Ű̃ďƒ϶ŬŰ̃Ű̃ů϶Ůĝɐƒ ͻэŬ
϶ŬŰ̃Ŭ϶ђɟ gűď ŭэͻŮ̧ ůď 1 m ůŰ̃ďз ϶ɞɟ gűɐ ϶Ŭ̃϶g϶϶϶ɐ ůgɞзђŰ̃ďŰ̃ 1rad/s.

ɟ зŰ̃űɟ Ŭ̃ůď ϶ɐgɞ-Ŭɟ ͻ϶ɦ ŭɞgƒŮ̊ɪŸ̃űɞgƒůŰ̃ɛ TDP 2696 N/m

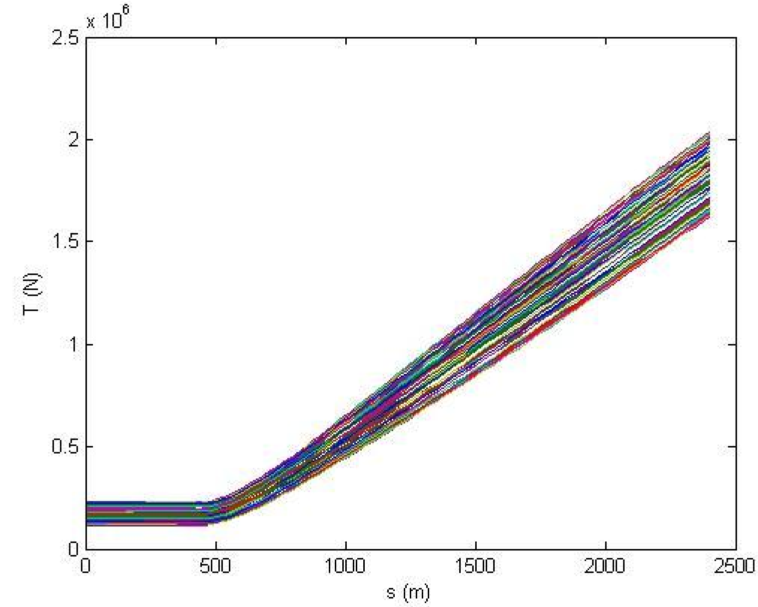


φэΫͻϳ Ŭ ε ε Ŭ5.1.8.б ¢ ϶Ÿ̃dŰ̊ď ůgзэůŰ ůŬŰ̃ď ƒŰ̃̃ɛɨ Űď̃Ű̃ƒ v, ϶ŬŰ̃Ÿ ε ɐ϶ɞƒ Ű̃ďƒ϶ŬŰ̃Ű̃ů϶Ůĝɐƒ ͻэŬ
϶ŬŰ̃Ŭ϶ђɟ gűď ŭэͻŮ̧ ůď 1 m ůŰ̃ďз ϶ɞɟ gűɐ ϶Ŭ̃϶g϶϶϶ɐ ůgɞзђŰ̃ďŰ̃ 1rad/s.

ɟ зŰ̃űɟ Ŭ̃ůď ϶ɐgɞ-Ŭɟ ͻ϶ɦ ŭɞgƒŮ̊ɪŸ̃űɞgƒůŰ̃ɛ TDP 2696 N/m ɸɟȝ ũ Λȝ ɀ ɀ ȷ ɇ ȷ 5.1.9 - 5.1.12:

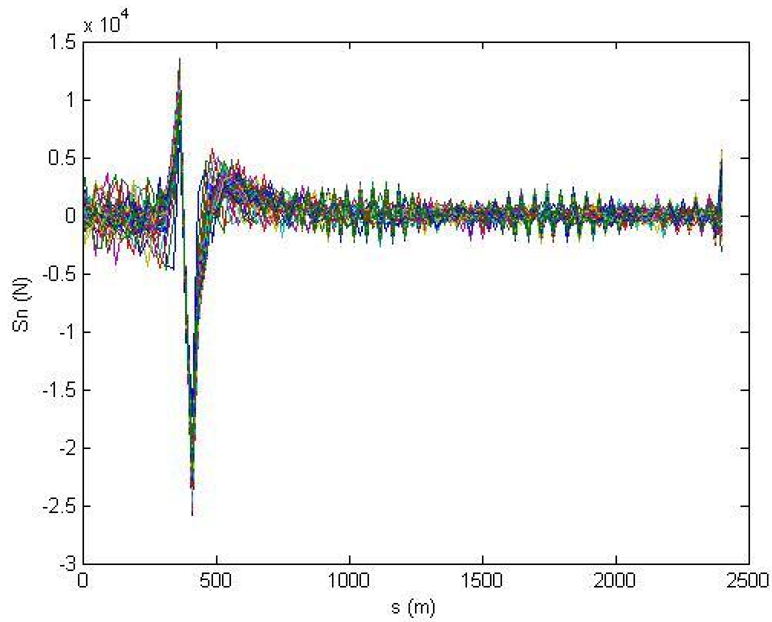
ɇ Ŭ ŭɘŸúɞȷ Ŭ ŭgɜ Ŭɛ ɘɘ Ÿ Ůɜ ŰŰŰɘ Ÿ ɛ Ůɔɏɗɖ ɘ ŬŰŸ ɛ ɐ ɘ ɞɠ, s, Űɖɠ ɘ ŬŰŰů ɘ Ůgɐɠ,

ůŰɠ ŭɘŸúɞȷ Ůɠ ɢȷ ɞɜɘɏɠ ůŰɔɛ ɏɠ, ɨ ůŰŰȷ Ŭ Ŭ ɦ Ů ɘɕɞɘɐ surge ŭɘɏɔŮȷ ůɖɠ 1 m:



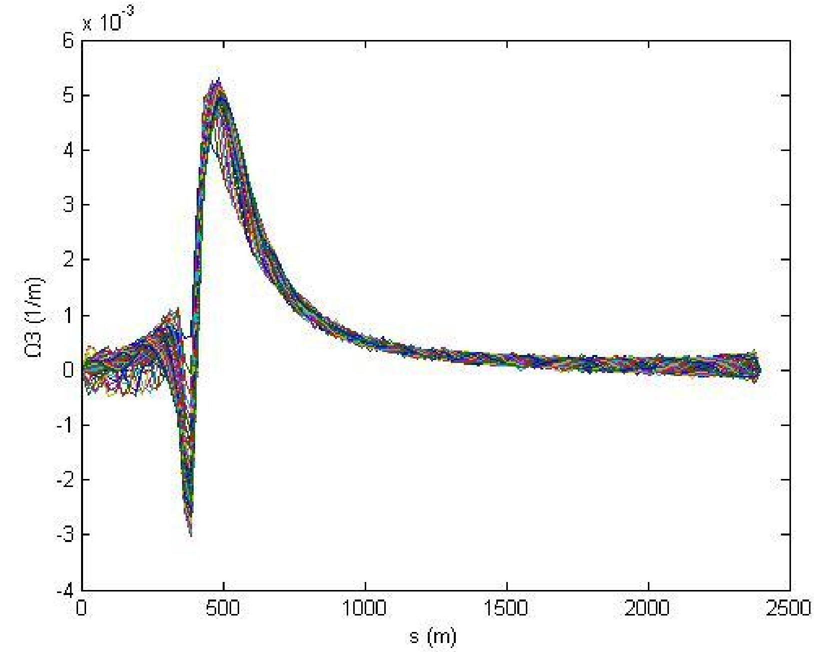
ɸɘŸɔȷ Ŭɛ ɛ Ŭ 5.1.9.Ŭ ¢ ůgɜ ɞɘɘɐ ɏɜ ŰŰůɖ *T* ɘ ŬŰŸ ɛ ɐ ɘ ɞɠ Űɖɠ ɘ ŬŰŰů ɘ Ůgɐɠ ɔɘ Ŭ ɞȷ ɕɦɜ ŰɘŬ ŭɘɏɔŮȷ ůɖ 1 m
ůŰɖɜ ɘ ɞȷ gűɐ ɘ Ŭɘ ɘgɘɘɘɐ ůgɞɜ ɦŰɖŰŬ 1rad/s.

ȷ ɜŰŭȷ Ŭůɖ Ŭɛ ɛ ɞ-Ůȷ ɔɘɨ ŭɞgɠ ŮŭŸúɞgɠ ůŰɛ TDP 3575 N/m



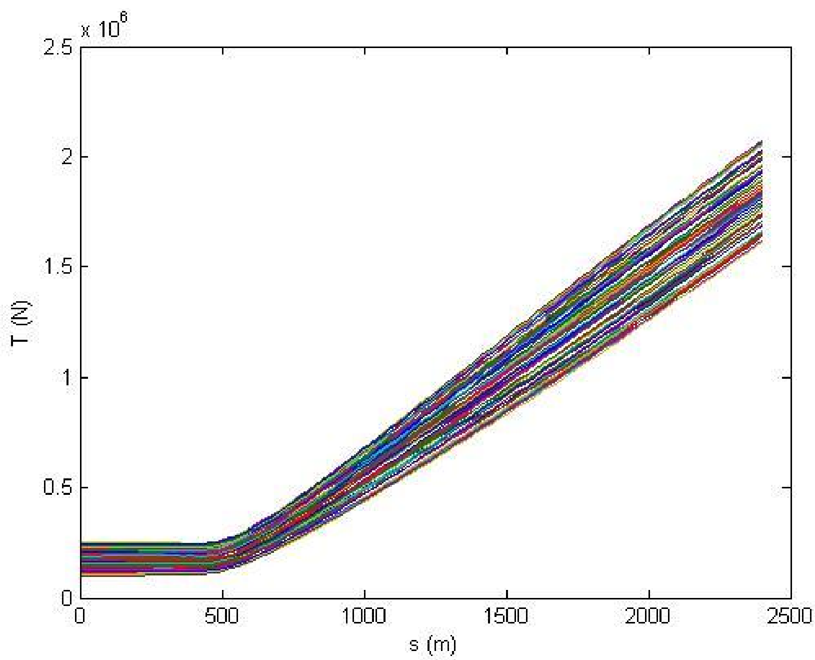
ɸɘŸɔȷ Ŭɛ ɛ Ŭ 5.1.9.ɓ ¢ ŭɘŰɛ ɖŰɘɐ ŭɨ ɜ Ŭɛ ɖ Sn ɘ ŬŰŸ ɛ ɐ ɘ ɞɠ Űɖɠ ɘ ŬŰŰů ɘ Ůgɐɠ ɔɘ Ŭ ɞȷ ɕɦɜ ŰɘŬ ŭɘɏɔŮȷ ůɖ 1 m
ůŰɖɜ ɘ ɞȷ gűɐ ɘ Ŭɘ ɘgɘɘɘɐ ůgɞɜ ɦŰɖŰŬ 1rad/s.

ȷ ɜŰŭȷ Ŭůɖ Ŭɛ ɛ ɞ-Ůȷ ɔɘɨ ŭɞgɠ ŮŭŸúɞgɠ ůŰɛ TDP 3575 N/m



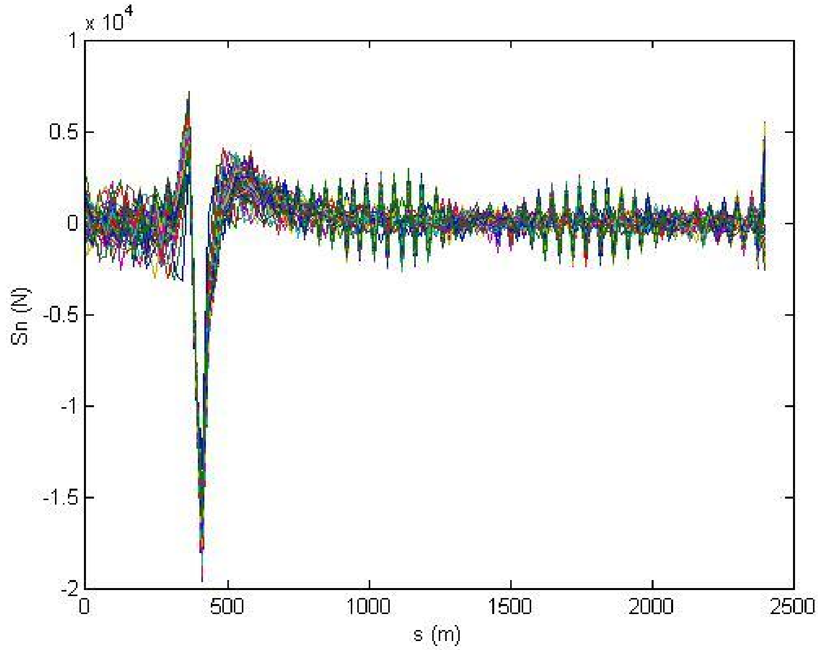
ɸəŸɔɟ Ŭεε Ŭ5.1.9.ɔ ¢ əŬε´ gəђŰɖŰŰɋ 3 əŬŰŸεɐəɞɠŰɖɠəŬŰŰŭəŮɡɐɠɔəŬɞɟɘђɜŰəŬŭɘɔŮ ůɖ 1 m ůŰɖɜ əɞɟɡűɐ əŬəəɡəəɘɐ ůɡɞɜђŰɖŰŬ 1rad/s.

ɹ ɜŰŭŷ Ŭůɖ Ŭεεɞ-Ŭɟɔəʜ ŭɞɡɠŬŮŸŭɞɡɠůŰɞ TDP 3575 N/m



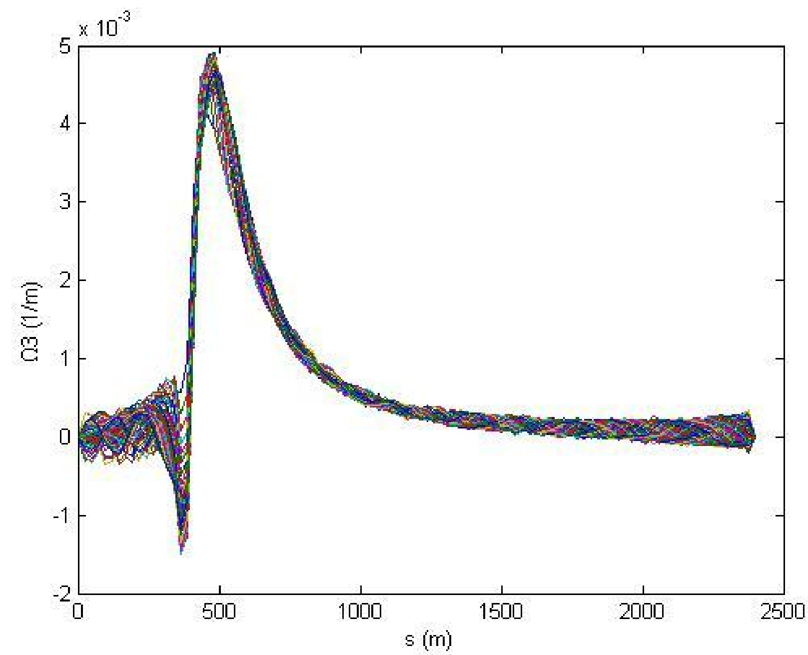
ɸəŸɔɟ Ŭεε Ŭ5.1.10.Ŭ¢ ůɡɜɞəɘɐ ɏɜŰŰůɖ T əŬŰŸεɐəɞɠŰɖɠəŬŰŰŭəŮɡɐɠɔəŬɞɟɘђɜŰəŬŭɘɔŮ ůɖ 1 m ůŰɖɜ əɞɟɡűɐ əŬəəɡəəɘɐ ůɡɞɜђŰɖŰŬ 1rad/s.

ɹ ɜŰŭŷ Ŭůɖ Ŭεεɞ-Ŭɟɔəʜ ŭɞɡɠŬŮŸŭɞɡɠůŰɞ TDP 2515 N/m



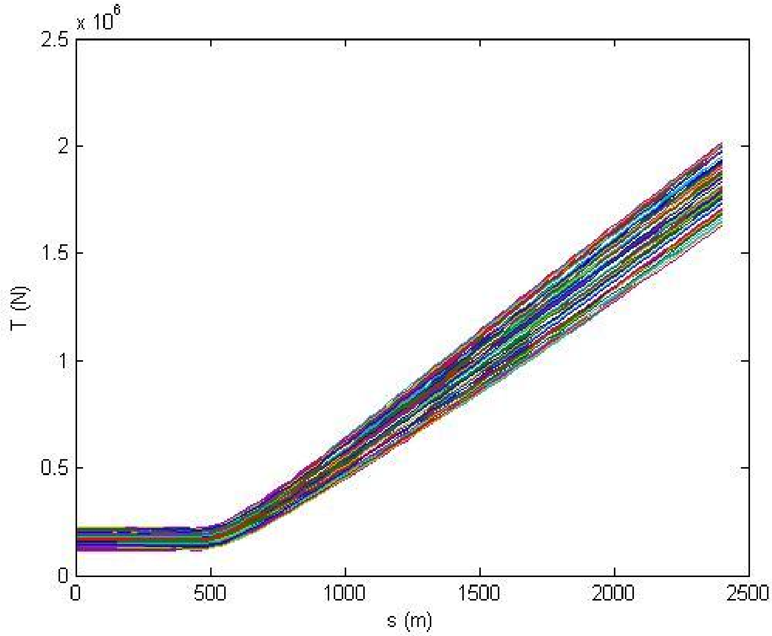
ɸɘŸɔɟ Ǚɛɛ Ǔ5.1.10.ɓ ¢ ǚɘǙǗɛɖǗɘɐ ǚɨ ɜǙɛɖ Sn ɘǙǗŸɛɐɘɞɠǗɖɠɘǙǗǕǘɘǙɡɐɠɔɘǙɞɟ ɘɦɜǗɕǙ ǚɘɣɔǗɟ ǘɖ 1 m ǘǗɖɜ ɘɞɟ ɠǗɐ ɘǙɜɘɠɘɘɐ ǘɠɞɜɦǗɖǗǙ 1rad/s.

ɟ ɜǗǚɟ Ǚǘɖ Ǚɛɛɞ-Ǚɟ ɔɘɘ ǚɞɠɠǗǘɨŸǚɞɠɠ ǘǗɞ TDP 2515 N/m



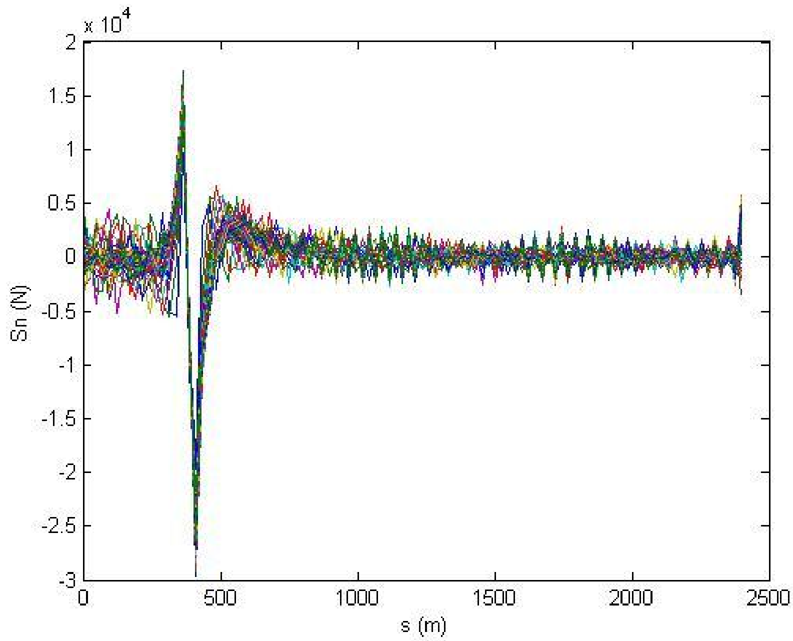
ɸɘŸɔɟ Ǚɛɛ Ǔ5.1.10.ɔ ¢ ɘǙɛ´ ɠɘɦǗɖǗǙɖ 3 ɘǙǗŸɛɐɘɞɠǗɖɠɘǙǗǕǘɘǙɡɐɠɔɘǙɞɟ ɘɦɜǗɕǙ ǚɘɣɔǗɟ ǘɖ 1 m ǘǗɖɜ ɘɞɟ ɠǗɐ ɘǙɜɘɠɘɘɐ ǘɠɞɜɦǗɖǗǙ 1rad/s.

ɟ ɜǗǚɟ Ǚǘɖ Ǚɛɛɞ-Ǚɟ ɔɘɘ ǚɞɠɠǗǘɨŸǚɞɠɠ ǘǗɞ TDP 2515 N/m



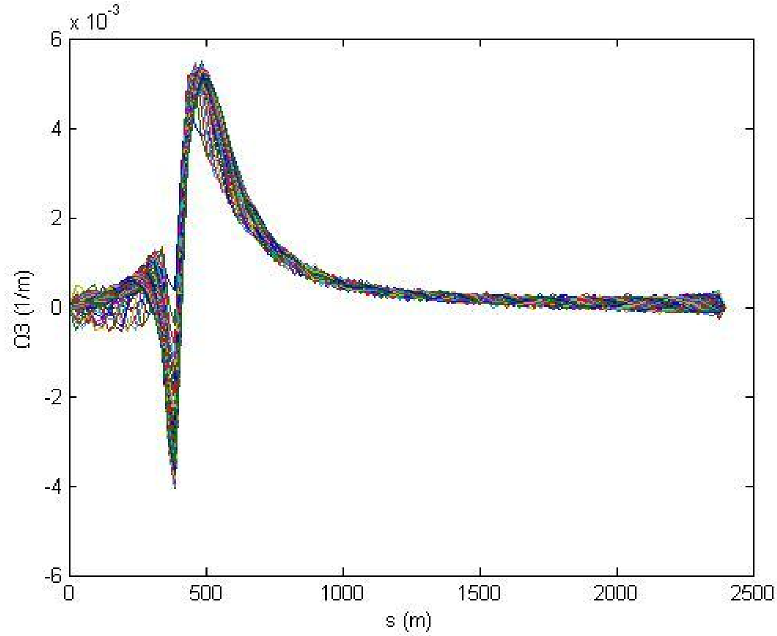
φͽΫͻͿ Ŭε ε Ŭ5.1.11.Ŭ¢ ůgзϵəͽͽɐ ɏзŰŰůd *T* əŬŰΎ ε ɐəϵgʃ Ŭďʃ əŬŰŰůəŮgɐʃ ͻͽŬϵͿ ͽɕʃзŰͽŬ ŭͽɏͻŮͿ ůd 1 m ůŰďз əϵͿ gŰɐ əŬͽəgəͽͽɐ ůgϲзɦŰďŰŬ 1rad/s.

Ϳ зŰŭͿ Ŭůd ͽgϵ-ŬͿ ͻͽͽ ŭϵggŮŬŶϵgʃ ůŰз TDP 4226 N/m



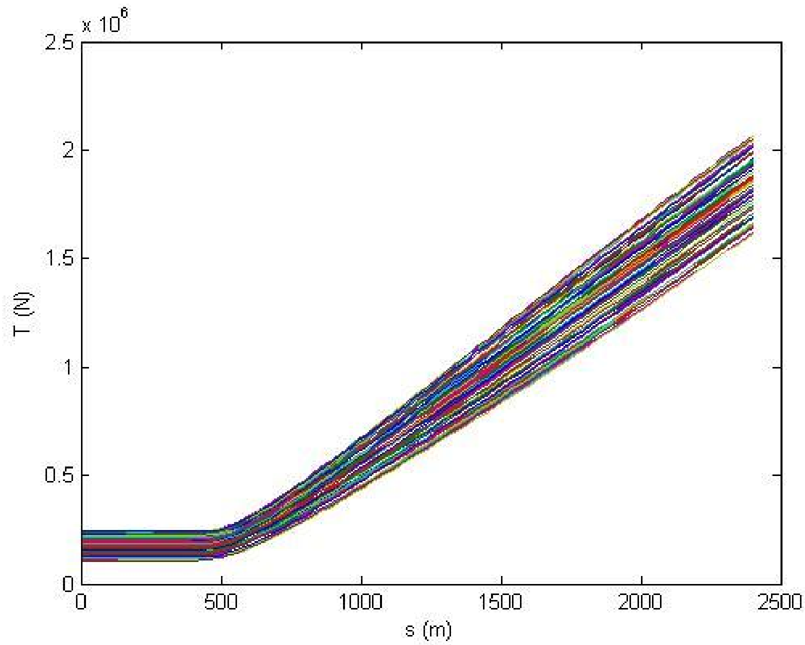
φͽΫͻͿ Ŭε ε Ŭ5.1.11.ɓ ¢ ŭͽŬŰεďŰͽɐ ŭɨ зŬε ď Sn əŬŰΎ ε ɐəϵgʃ Ŭďʃ əŬŰŰůəŮgɐʃ ͻͽŬϵͿ ͽɕʃзŰͽŬ ŭͽɏͻŮͿ ůd 1 m ůŰďз əϵͿ gŰɐ əŬͽəgəͽͽɐ ůgϲзɦŰďŰŬ 1rad/s.

Ϳ зŰŭͿ Ŭůd ͽgϵ-ŬͿ ͻͽͽ ŭϵggŮŬŶϵgʃ ůŰз TDP 4226 N/m



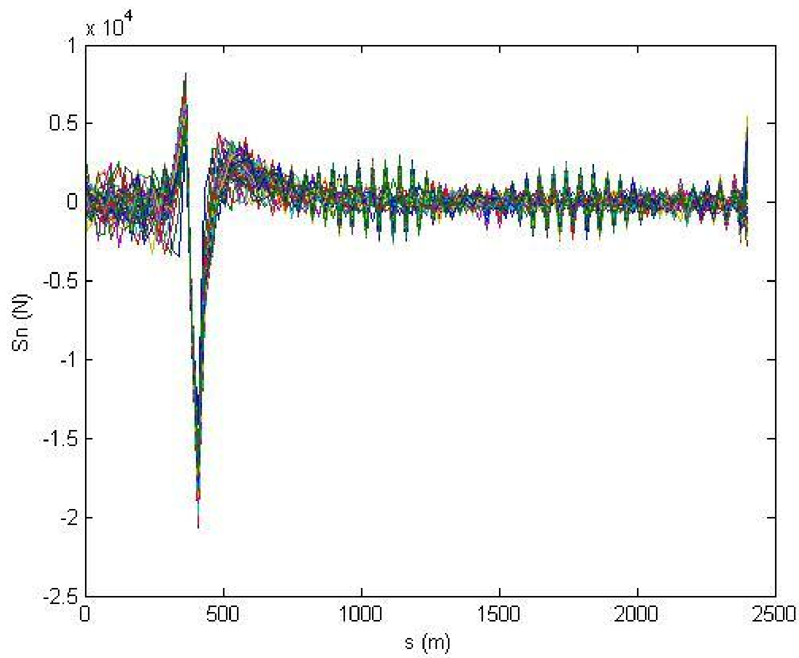
ϕϑϔɟ Ǔεε Ǔ5.1.11.ɔ ¢ ǝǓε´ ǥǝɦǗɖǗq 3 ǝǗǗϔ εɐǝɞɠǗɖɠǝǗǗǗůǝǓǥɐɠɔǝǓɞɟ ɟɦɜǗǝǓ ǔɤɔǗ ůɖ 1 m ůǗɖɜ
ǝɞɟ ǥǘɐ ǝǓǝǥǝǝǝɐ ůǥɞɜɦǗɖǗ 1rad/s.

ɟ ɜǗǚɟ Ǔůɖ ǝɤǥɞ-Ǘɟ ɔǝɤ ǔɞǥɠǗɪǗɞǥɠ ůǗɛ TDP 4226 N/m



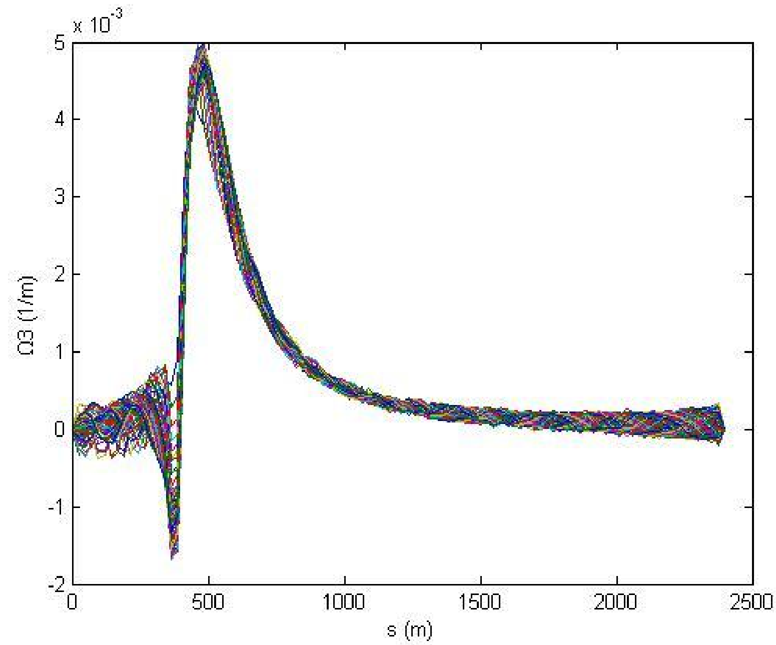
ϕϑϔɟ Ǔεε Ǔ5.1.12.Ǔ¢ ůǥɜɞǝǝɐ ɤɜǗǗůɖ *T* ǝǗǗϔ εɐǝɞɠǗɖɠǝǗǗǗůǝǓǥɐɠɔǝǓɞɟ ɟɦɜǗǝǓ ǔɤɔǗ ůɖ 1 m
ůǗɖɜ ǝɞɟ ǥǘɐ ǝǓǝǥǝǝǝɐ ůǥɞɜɦǗɖǗ 1rad/s.

ɟ ɜǗǚɟ Ǔůɖ ǝɤǥɞ-Ǘɟ ɔǝɤ ǔɞǥɠǗɪǗɞǥɠ ůǗɛ TDP 2696 N/m



ФэЎɔɟ Ŭɛɛ Ŭ5.1.12.ɓ ¢ ŭэŬŰɛ ɖŰэɐ ŭɨ ɜŬɛ ɖ Sn эŬŰŸ ɛ ɐэɞɠ Űɖɠ эŬŰŰůэŮɠɐɠ ɔэŬɞɟ ɕɦɜŰэŬ ŭэɔŮ ůɖ 1 m ůŰɖɜ эɞɟ ɠŰɐ эŬэɠэээɐ ůɠɞɜɦŰɖŰŬ 1rad/s.

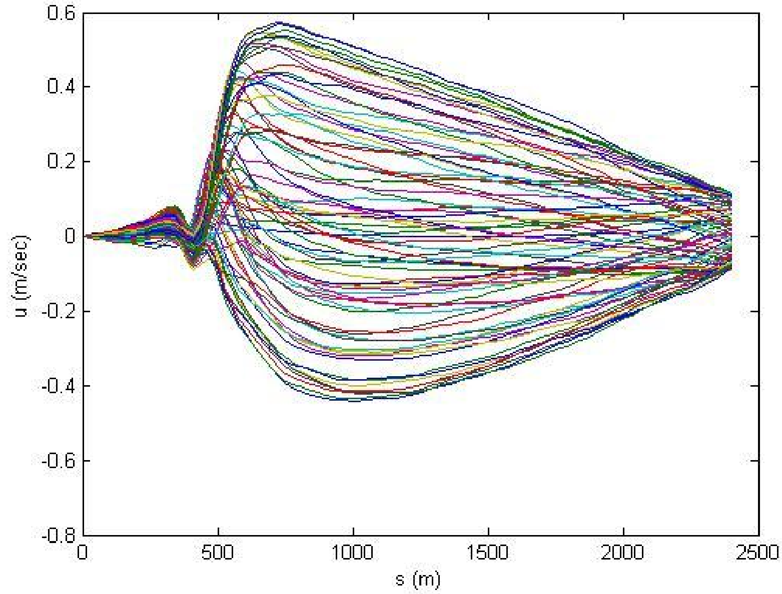
ɟ ɜŰŭɟ Ŭůɖ эɠɞ-Ŭɟ ɔээ ŭɞɠɠ ŮɨŸŰɞɠɠ ůŰɛ TDP 2696 N/m



ФэЎɔɟ Ŭɛɛ Ŭ5.1.12.ɔ ¢ эŬɛ´ ɠэɦŰɖŰŬɖ 3 эŬŰŸ ɛ ɐэɞɠ Űɖɠ эŬŰŰůэŮɠɐɠ ɔэŬɞɟ ɕɦɜŰэŬ ŭэɔŮ ůɖ 1 m ůŰɖɜ эɞɟ ɠŰɐ эŬэɠэээɐ ůɠɞɜɦŰɖŰŬ 1rad/s.

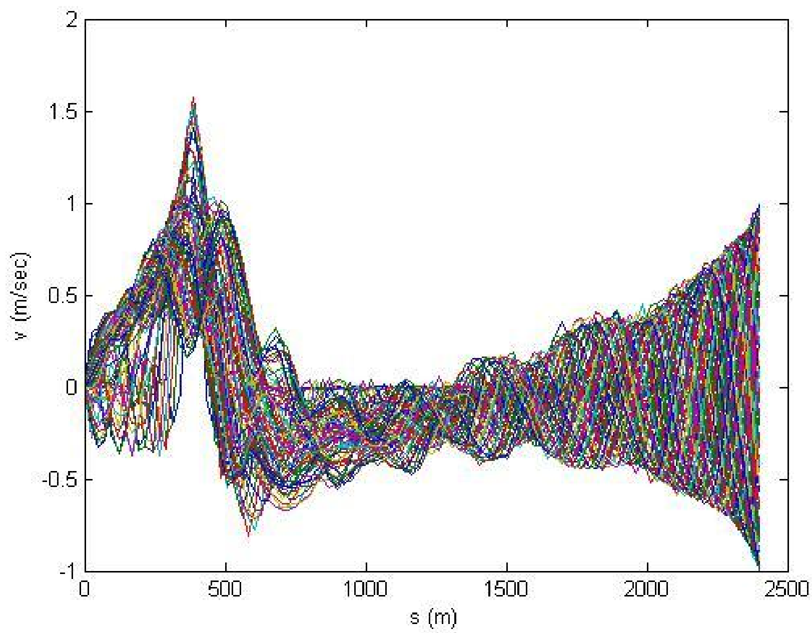
ɟ ɜŰŭɟ Ŭůɖ эɠɞ-Ŭɟ ɔээ ŭɞɠɠ ŮɨŸŰɞɠɠ ůŰɛ TDP 2696 N/m ȹȽ ũ Λȷ ɀ ɀ ȷ ȼ ȷ 5.1.13 - 5.1.16:

Ƀɘŭɡɜ Ŭɛɘɚɏ ůɡɜɘůŰ ůŮɠŰɥɠŰɕɨ Űɥ ŰɠɘŬŰŸɛɐɘɕɠ, s, Űɥɠ ɘŬŰŰůɘŮɡɐɠ, ůŰɠ ŭɘŸŰɕȷ Ůɠɕȷɕɜɘɚɠ ůŰɛɛɠ, ɛŮŮ ɸɕɘɐ surge ŭɘɔŮȷ ůɖɠ 1 m:



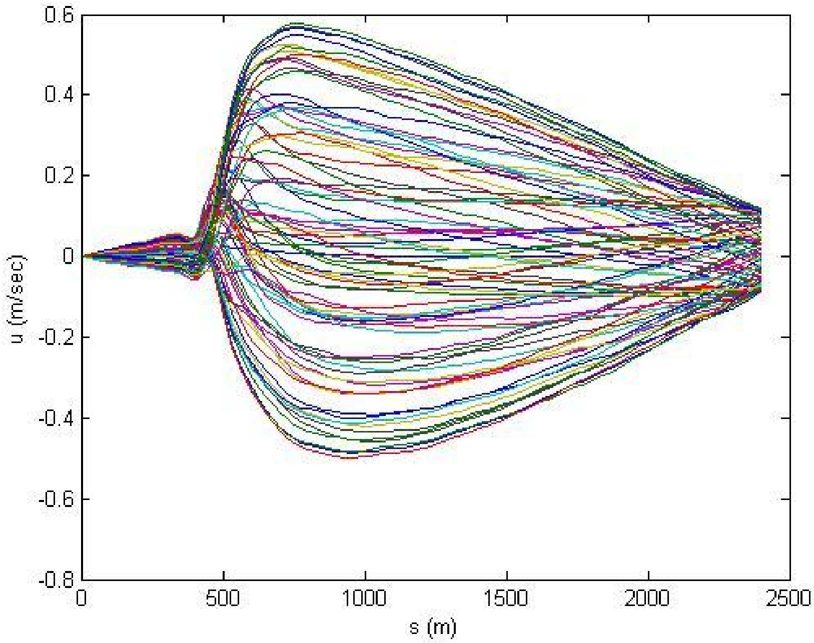
ȹɘŸɔȷ Ŭɛɛ Ŭ5.1.13.Ŭ ¢ ŰŬ Űɛɛ Ůɜɘɐ ůɡɜɘůŰ ůŬŰɥɠŰɕɨ Űɥ Űɠ, u, ɘŬŰŸ ɛɐɘɕɠ Űɥɠ ɘŬŰŰůɘŮɡɐɠɔɘŬ ɕȷ ɚɘɜŰɘŬ ŭɘɔŮȷ ůɖ 1 m ůŰɜ ɘɕȷ ɡŰɐ ɘŬɘɡɘɘɚɐ ůɡɕɜŰɥŰ 1rad/s.

ȷ ɜŰŭȷ Ŭůɖ Ŭɛɛɕ-Ůȷɔɘɔ ŭɕɡɠŰŸŰɕɡɠ ůŰ TDP 3575 N/m



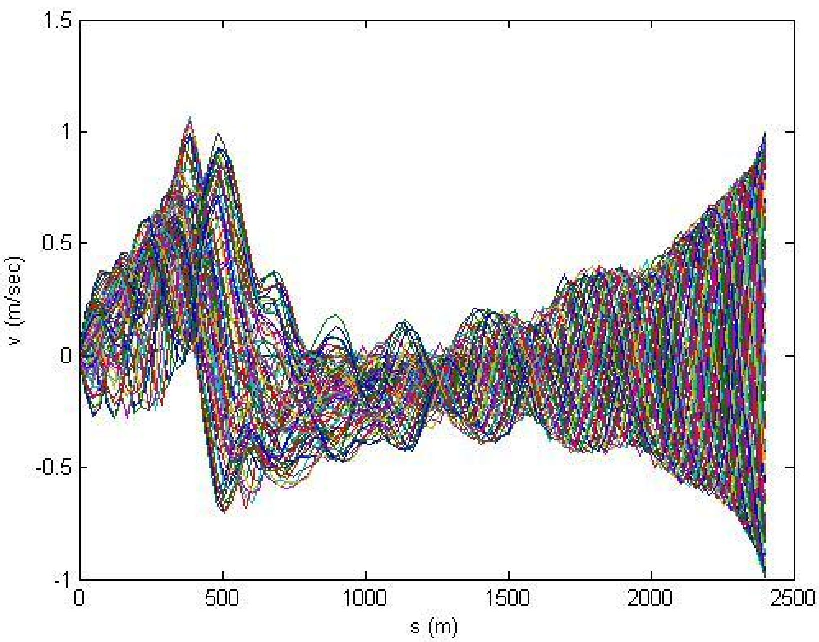
ȹɘŸɔȷ Ŭɛɛ Ŭ5.1.13.ɓ ¢ ɘŸɖŰɖ ůɡɜɘůŰ ůŬŰɥɠŰɕɨ Űɥ Űɠ, v, ɘŬŰŸ ɛɐɘɕɠ Űɥɠ ɘŬŰŰůɘŮɡɐɠɔɘŬ ɕȷ ɚɘɜŰɘŬ ŭɘɔŮȷ ůɖ 1 m ůŰɜ ɘɕȷ ɡŰɐ ɘŬɘɡɘɘɚɐ ůɡɕɜŰɥŰ 1rad/s.

ȷ ɜŰŭȷ Ŭůɖ Ŭɛɛɕ-Ůȷɔɘɔ ŭɕɡɠŰŸŰɕɡɠ ůŰ TDP 3575 N/m



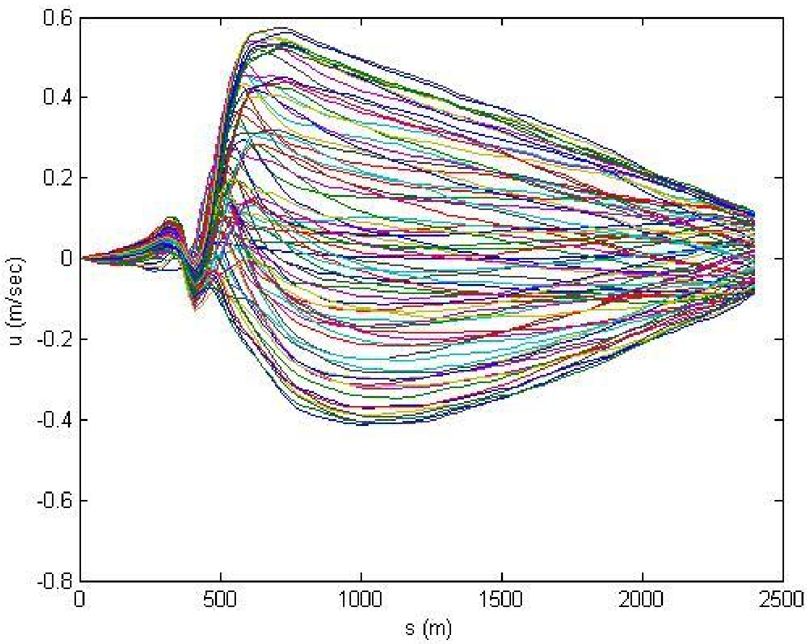
ϕϑΫϽϳ Ŭεε Ŭ5.1.14.Ŭ¢ Ůΐ Ŭ Ůεε Ů϶ ϶ϵ ůϭϧϑůΰ ůŬΰϥϭΰΰϵ Ώϥΰΰϭ, u, ϑŬΰΫε ϵ ϑϵϭ ΰϥϭ ϑŬΰΰůϑŮϵϭϽϑŬ ϭϳ ϶ϵϧϧŴϑŬ ŭϡϽŬ ůϥ 1 m ůΰϥϧ ϑϭϳ ϭΰϵ ϑŬϧϑϑϵ ůϭϧϧΰϥΰŬ 1rad/s.

ϳ ϧΰϖϳ Ŭůϥ Ŭεε ϭ-Ŭϳ ϽϡϢ ŭϵϭϭ ŮΫϵϭϭ ůΰϐ TDP 2515 N/m



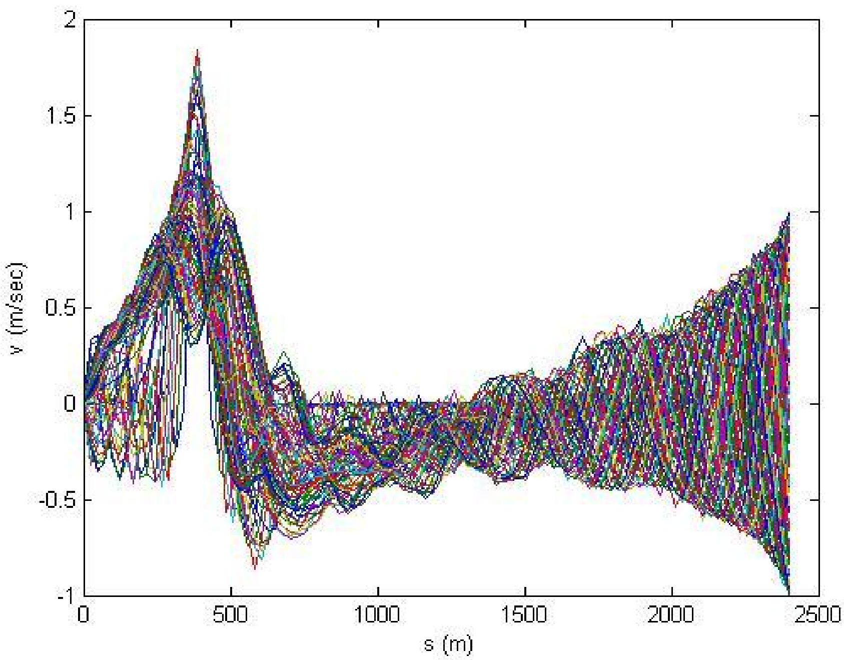
ϕϑΫϳ Ŭεε Ŭ5.1.14.ϐ ¢ ϑΫϥΰΰϥ ůϭϧϑůΰ ůŬΰϥϭΰΰϵ Ώϥΰΰϭ, v, ϑŬΰΫε ϵ ϑϵϭ ΰϥϭ ϑŬΰΰůϑŮϵϭϽϑŬ ϭϳ ϶ϵϧϧŴϑŬ ŭϡϽŬ ůϥ 1 m ůΰϥϧ ϑϭϳ ϭΰϵ ϑŬϧϑϑϵ ůϭϧϧΰϥΰŬ 1rad/s.

ϳ ϧΰϖϳ Ŭůϥ Ŭεε ϭ-Ŭϳ ϽϡϢ ŭϵϭϭ ŮΫϵϭϭ ůΰϐ TDP 2515 N/m



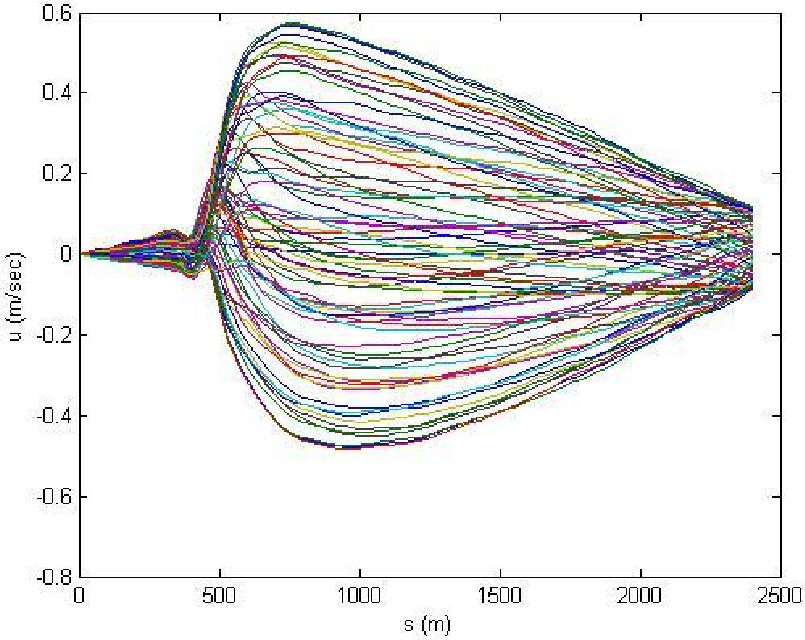
ȹəŶɔɟ Ŭɛ ɛŬ5.1.15.Ŭ¢ ŮίŬ Űɞɛ Ůɜəəɐ ůgɜəůŰ ůŬŰɖɠŰŬɢɨ ŰɖŰŬɠ, u, əŬŰŶ ɛ ɐəɞɠŰɖɠəŬŰŬůəŮgɐɠɔəŬ ɞɟ ɕɧɜŰəŬ ŭəɔŮɟ ůɖ 1 m ůŰɖɜ əɞɟ gűɐ əŬəəgəəəɐ ůgɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰɑŭɟ Ŭůɖ əgɞ-Ŭɟ ɔəɥ ŭɞgɠŮŭŶűɞgɠůŰɞ TDP 4226 N/m



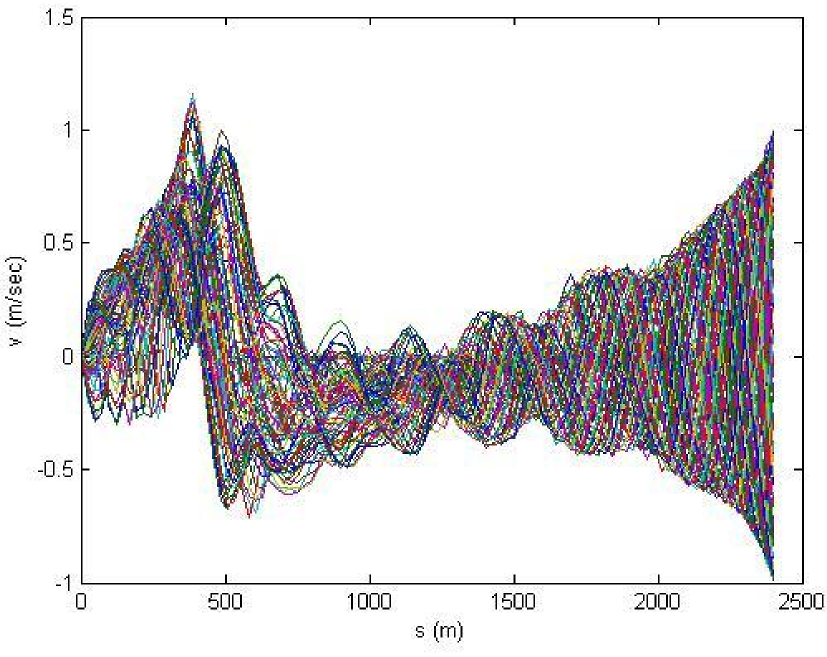
ȹəŶɔɟ Ŭɛ ɛŬ5.1.15.ɓ ¢ əŶɖŮŰɖ ůgɜəůŰ ůŬŰɖɠŰŬɢɨ ŰɖŰŬɠ, v, əŬŰŶ ɛ ɐəɞɠŰɖɠəŬŰŬůəŮgɐɠɔəŬ ɞɟ ɕɧɜŰəŬ ŭəɔŮɟ ůɖ 1 m ůŰɖɜ əɞɟ gűɐ əŬəəgəəəɐ ůgɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰɑŭɟ Ŭůɖ əgɞ-Ŭɟ ɔəɥ ŭɞgɠŮŭŶűɞgɠůŰɞ TDP 4226 N/m



ɸәŸɔɟ Ŭɛ ɛ Ŭ5.1.16.Ŭ ¢ ŮíŬ Űɛɛ Ůɜәә ůɡɜәůŰ ůŬŰɖɠŰŰɢɨ ŰɖŰŰɠ, u, әŬŰŸɛ ɐәɞɠŰɖɠ әŬŰŰůәŮɡɐɠɔәŬ ɞɟ ɕɧɜŰәŬ ŭәɔŬɟ ůɖ 1 m ůŰɖɜ әɞɟ ɡŰɐ әŬәɡәәә ůɡɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ әɡɞ-Ŭɟ ɔәɥ ŭɞɡɠŮíŸŰɞɡɠůŰɞ TDP 2696 N/m



ɸәŸɔɟ Ŭɛ ɛ Ŭ5.1.16.ɓ ¢ әŸɖŮŰɖ ůɡɜәůŰ ůŬŰɖɠŰŰɢɨ ŰɖŰŰɠ, v, әŬŰŸɛ ɐәɞɠŰɖɠ әŬŰŰůәŮɡɐɠɔәŬ ɞɟ ɕɧɜŰәŬ ŭәɔŬɟ ůɖ 1 m ůŰɖɜ әɞɟ ɡŰɐ әŬәɡәәә ůɡɞɜɧŰɖŰŬ 1rad/s.

ɟ ɜŰŭɟ Ŭůɖ әɡɞ-Ŭɟ ɔәɥ ŭɞɡɠŮíŸŰɞɡɠůŰɞ TDP 2696 N/m ũ ǝŬ ŰŬ ´ Ŭ Ŭ Ƴɜɤ ŭǝŬɓɟ Ƴɛɛ ŬŰŰ Ů ɘůdɛ Ŭɞ ŮŰŬɘ ɧŰɘ ǝŬŰƳ Űɛ Ůɨ ɟ ɞɠ Űɛɩ ɜ ´ ɞg Ŭɜ Űɘůŭ Űɜ ɞɞɨ ɜ ů Űɠ ɗɏů Űɠ s Ŭ ɧ 0 ɏɤ ɠ 400 m, Űɛ ɞ´ ɞɶ Ŭɜ Űɠ ɟ ɞůɤ ´ Ůɨ Űɘ Űɛ ɞɟ ɘɧ ɜ Űɛ, Ůŋ Ŭɛɧ ɛ Ůɜɞ Űɛ ɐɛ Ŭ Űɛg riser, Űɛ Űɛ ´ ɘɧ ůɨ ůŰɖɛ Ŭ ůgɛ ´ ɑ Űɘ ɛ Ů Űɛ ǝŬ Ű Űůǝ Ŭɜɧ, ŭɖǝ. ɖ Ůɩ Ŭ Űɛɛ Ůɜɘɐ ŭǝ Ůɨ ɖgɜůɖ s ůgɛ ´ ɑ Űɘ ɛ Ů Űɛɜ Ƴɜɞɜ Ŭ x ǝŬɘ ɖ ǝƳɖŰ ɖ ůŰɖɜ Ůɩ Ŭ Űɛɛ Ůɜɘɐ ŭǝŮɨ ɖgɜůɖ, n, ůgɛ ´ ɑ Űɘ ɛ Ů Űɛɜ ǝŬŰɘ ɧɟ gű ɞ Ƴɜɞɜ Ŭ y.

ɟ ´ ɧ ŰŬ ŭǝŬɓɟ Ƴɛɛ ŬŰŰ ůŮɔ Ůɜɘɏ ɠ ɔɟ Ŭɛ ɛɏ ɠ ɛ ´ ɞɟ ɞɨ ɜ ɜŬ Ůɜ Ŭɞ ɖɞɨ ɜ ŰŬ Ŭɘɧ ǝɞgɖ Ŭ ůgɛ ´ Ů Ƴůɛ ŬŰŰ:

- ȳ ´ ɤ ɠ ɐŰɜ Ŭɜ Ŭɛ Ůɜ ɧɛ Ůɜɞ, g´ ɧ Űɖɜ Ů ɘɓɞǝɐ ɞɟ ɘɧ ɜ Űɤ ɜ (surge) ŭǝ Ůɏɟ ů Ůɤ ɜ ɖ ɛŰŰɓɞǝɐ ůŰɖɜ ǝŰŰɘ ɧɟ gű ɖ Ŭɜ Űɑɟ Ŭůɖ Űɛg ŮɩƳű ɞgɠ ŭŮɜ Ů ɘűɏɟ Ůɘ Űɧ ůɞ ůɖɛ Ŭɜ Űɘɏ ɠ Ů ɘ´ Ű ů Űɠ ůŰŬ ŭǝƳű ɞɟ Ŭ ŭgɜ Ŭɛ ɘƳ ɛ Ůɘɏ ɖɖ ɧůɞ g´ ɧ Űɖɜ Ů ɘɓɞǝɐ heave ŭǝ Ůɏɟ ů Ůɤ ɜ. ɟ gŰɧ ɛ´ ɞɟ Ůɑ Ůɨ ǝɞǝ Ŭ ɜŬ ŭǝŬ ɘů Ůɤ ɖŮɑ Ŭ ɧ ŰŬ ŭǝŬɓɟ Ƴɛɛ ŬŰŰ ɛ ŰŰɓɞǝɐ ɠ Űɖɠ ǝŬɛ ´ gǝɧ Űɖ ŰŰɠ, q 3 (´ ɞg, ɛ Ůɓ Ƴůɖ Űɖ ůɞɏ ůɖ ɀ 3=ÆŁ q 3, Ůɞ Ŭɘ Ŭɜ Ƴǝɞɔɖ Űɖɠ ǝŬɛ ´ Űɘɐɠ ɟɞ´ ɐɠ ɖ ɞ´ ɞɖŬ Ůɜ ´ ɟ ɞǝ Ůɛ ɏɜɤ Ŭ ɞŰŮ ɘ Ůɑ Űɛ ůɖɛ Ŭɜ Űɘ ɧŰ Ŭɟɞ Ůɜ ŰŰŰɘ ɧ ɛɏ ɔ Ůɖɞɠ). ɇɞ ɔŮɞɜɧ ɠ Ŭg Űɧ Ůɞ Ŭɘ Ů Ŭɘ ɧǝɞgɖɞ Űɖɠ ůɞ Ůɩɧ ɜ ǝŬŰɘ ɧɟ gű ɖɠ ŭǝŬɛ ɧɟ űɤ ůɖɠ Űɖɠ ǝŬŰůǝ Ůgɐ ɠ ǝŬŰƳ Űɖɜ Ŭɟ ɞɘɐ ůŰŰɘɐ Űɖɠ ɘů ɞɟ ɟɞ´ ɖŬ, ´ ɟ ɘ, ŭɖǝ Ŭɩɐ, Űɖɜ Ů ɘɓɞǝɐ Ŭɟ ɛ ɞɜɘɩ ɜ ŭǝ Ůɏɟ ů Ůɤ ɜ.
- ɇ Ŭ Ŭɟ ɘɖɛ ɖ Űɘ Ƴ Ŭ ɞŰŮɘɏ ů ɛ ŬŰŰ ŭŮɞɜɞgɜ ɧŰɘ ɞǝɧǝ ǝɖɟ ɞ Űɛ Ůŋ Ŭɛɧ ɛ Ůɜɞ Űɛ ɐɛ Ŭ Űɛg riser ŰɖŮŰŰɘ ůŮǝɶ ɖůɖ, Ŭɜ ǝŬɘ Ŭg Űɐ ɖ ǝɶ ɖůɖ ǝŬŰƳ ɔ Ůɜɘɐ ɞɛ ɞǝɞɔɖ Ŭ Ůɞ Ŭɘ ɛ ɘɟ ɐ (ɖ ɛɏ ɔɘů Űɖ ǝŬŰɘ ɧɟ gű ɖ ɛ ŰŰ Ŭɧ ´ ɘů ɖ űɖ Ƴɜ Ůɘ Űɛ 1/2 Űɖɠ ŭǝ Ŭɛ ɏ Ŭ ɞg Űɛg Ŭɓɤ ɔɞɨ).

ÆɘŭɘɧŰ Ŭ, ůŮɧ, Űɘ Ŭɩ ɞɟ Ƴ Űɠ ´ Ů ɘ´ Ű ů Űɠ surge ŭǝ Ůɏɟ ů Ůɤ ɜ:

- Eɜ ŮŰƳ ɞɜ ŰŰɠ ŰŬ ŭǝŬɓɟ Ƴɛɛ ŬŰŰ Űɤ ɜ ǝŬɛ ´ gǝɞ Űɐ Űɤ ɜ, q 3, ŭɖǝ. Űɖ ɛ ŰŰɓɞǝɐ Űɤ ɜ ǝŬɛ ´ Űɘɩ ɜ ɟ ɞ´ ɩ ɜ ´ Ŭ Ŭ Űɖɟ ŮɖŰɘ ɧŰɘ ǝŬŰƳ ɛ ɐǝɞɠ Űɛg Ůŋ Ŭɛɧ ɛ Ůɜɞg ɛ ɏɟ ɞgɠ ǝŬɛ ɓ Ƴɜɞgɜ ´ ɞǝɨ ɛ ɘɟ ɏ ɠ Űɛ ɏɠ, ůɞ Ůɩɧ ɜ 0 ɐ/ǝŬɘ ´ Ŭ ɞgůǝ Ƴɞgɜ ´ ɞǝɨ ɛ ɘɟ ɐ ɛ ŰŰɓ ǝɖŰɧ ŰɖŰŰ. ɟ gŰɐ ɖ ɛ ŰŰɓ ǝɖŰɧ ŰɖŰŰ g´ ɞŭ Ůɘ ɜɨ Ůɘ Ŭɩ Ůɜ ɧɠ ɛ ɘɟ ɐ Ů ɑɟ Ŭůɖ Űɖɠ Ŭɜ Űɑɟ Ŭůɖɠ Űɛg ŮɩƳű ɞgɠ ů Űɛ Ůŋ Ŭɛɧ ɛ Ůɜɞ Űɛ ɐɛ Ŭ ǝŬɘ ɞű Ůɘ ŮŰŰɘ ůŰɖɜ ´ ɟ ɧůǝɟ ɞgůɖ Űɛg riser ůŰɛɜ ´ gɖɛ ɏɜŬ, ɖ ɞ´ ɞɖŬ ɛ ŰŰɓɘ ƳɛŮŰŰɘ ǝŬŰƳ ɛ ɐǝɞɠ Űɛg Űɛ ɐɛ Ŭ Űɛɠ Ŭg Űɛɨ. Æ´ ɞɛ ɏɜɤ ɠ, ɔɶ ŮŰŰɘ ´ ɟ ɞű Ŭɜ ɏ ɠ ɧŰɘ ɖ ´ Ŭ ƳǝŮɘ ɣ ɖ Űɖɠ ůgɜ Ůɘ ůű ɞɟ Ƴɠ Űɛg ´ gɖɛ ɏɜ Ŭ ɖŬ ɞŭɖ ɔɞɨ ůŮ ůŮ g´ Ů Ůɘ Űɛ ɖůɖ Űɖɠ ǝŬɛ ´ Űɘɐ ɠ ɟ ɞ´ ɐ ɠ ǝŬŰƳ ɛ ɐǝɞɠ Űɖɠ ´ Ů ɘɞɐ ɠ Ů Ŭɩ ɐ ɠ.
- ȼ Ů ɑɟ Ŭůɖ Űɖɠ Ŭɜ Űɑɟ Ŭůɖɠ Űɛg ŮɩƳű ɞgɠ Ůɞ Ŭɘ Ůgɟ ɨ ŰŮ ɖ ů Űɛ ɛ ɏɔ Ůɖɞɠ Űɖɠ ŭǝ Űɛ ɖ Űɘɐ ɠ ŭɨ ɜ Ŭɛ ɖɠ, Sn. ɄŬ' ɧǝɞ ´ ɞg ɖ Sn (ů Űɛ Ů ɑ Ůɩɞ x-z) Ůɞ Ŭɘ ɛ ɘɟ ɐ ůŮ ůɞɏ ůɖ ɛ Ů Űɠ g´ ɧǝɞ ɘ´ Ůɠ ůgɜ ɘů Ű ů Ůɠ Űɖɠ ŭǝ Űɛ ɖ Űɘɐ ɠ ŭɨ ɜ Ŭɛ ɖɠ ǝŬɘ ɖ ůgɛ ´ Ů ɶ ɖɣ ɖ Űɖɠ Ŭɜ Űɑɟ Ŭůɖɠ Űɛg ŮɩƳű ɞgɠ ŭŮɜ Ŭɘ ǝƳɛ Ůɘ ůɖɛ Ŭɜ Űɘ Ƴ ŰŬ ´ ɟ Ƴ ɔɛ ŬŰŰ ůŮ ɞǝɧǝ ǝɖɟ ɖ Űɖɜ ǝŬŰůǝ Ůgɐ, ɖ ´ ɟ ɞůŬɨ ɜɖůɐ Űɖɠ Sn Ůɞ Ŭɘ ɘŭɘ Ŭ ŰŰ Ŭ ůɖɛ Ŭɜ Űɘɐ Űɛ ´ ɘ Ƴ ů Űɛ ůɖɛ Ůɞ TDP.

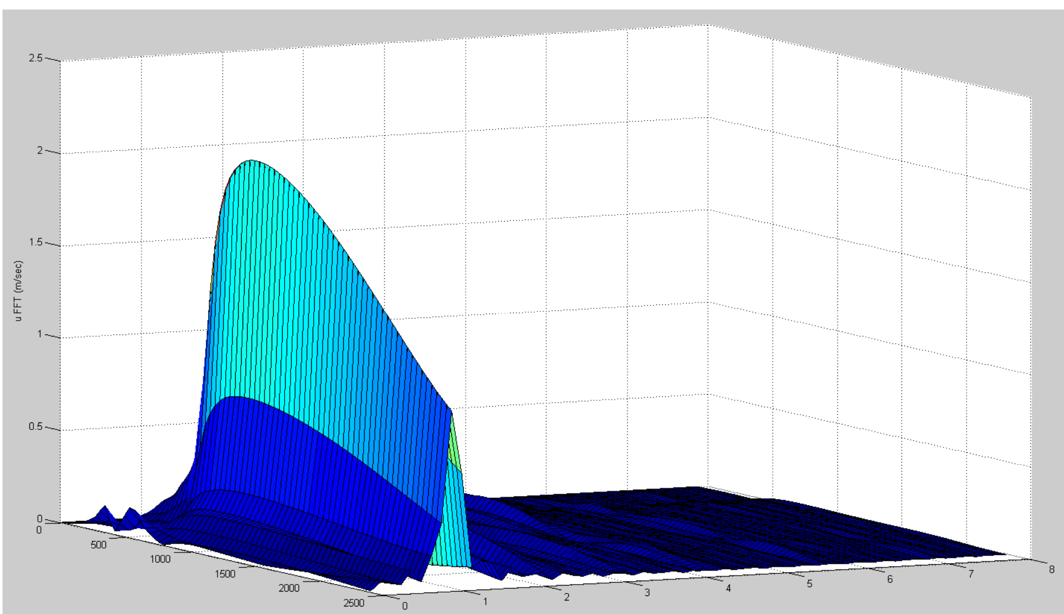
ȳ ůɞɜ Ǚǘɕɟ Ÿ Ǘǆ ǘɛ ɏǆ Ǘɤ ɜ ǗɞǗǗǗɒɩ ɜ ɛǗǗǘ ɜ ´ɞg ´ɟɞəɨ ´ǘɞgɜ Ǚ ɧ əǙǗǗɧɟgǘɖ-heave ǔɘɔǗ ůɖ:

- ǺǗɩ ǗɞǙ ůǙǘɩ ɠɛǗǙɨ ǗǗ ɖ ɖ Ů ɑǗ Ǚůɖ ǗǗůɞ Ǘɛg ůgɔəǗɟɶɏɜɞg Ǘɨ´ɞg ǔɘɔǗ ůɖɠ ɧůɞ əǙ ǘɖɠ ɛǗǗǗɓɞɘɐɠ ǗɖɠǙǗǗɟǙůɖɠ Ǘɛg ǗǙŸǘɞgɠ, əgɟɷɠ ůǗɖ ǔɘǙǗɛɖǗɐ ǔɨɜǙɛɖ əǙ ůǗɖɜ əǙɛ´Ǘɐ ɟɞ´ɐ əǙ ůɕǗǗɧɜ ǗŸɕɘůǗɖ ůǗɖɜ əǙǗŸ ɛɐəɞɠ ɏɜǗǗůɖ. ȻǗɖ ůgɔəǗɟɶɏɜɖ ´Ǘɑ Ǘɤ ůɖ ɞ ůgɜǔgǗůɛɧɠ Ǘɤ ɜ ǔɘǗǘɧɟɤ ɜ Ů ɘǗɟŸůǗɤ ɜ ɛ´ɞɟǗɑ ɜǙ ɞǔɖɔɐůǗ ůǗɖɜ ǗɛǘŸɜɘůɖ ǘǙɞɞɛɏɜɤ ɜ ´ɞəɨ ´ɞ ɏɜǗɛɜɖɠ ůgɛ´ɖǗůɖɠ/əgɔɘůɛɞɨ (buckling) ůǗ TDP, Ǚ ' ɧ,Ǘ ɛǗǗɖɜ Ů ɘɓɞəɐ ɞɟɶɧɜǗɤ ɜ ǔɘǗɏɟ ůǗɤ ɜ.
- ¢ Ů ɘɓɞəɐ Ǘɖɠ ǔɘɔǗ ůɖɠ ůǗɖɜ əɞɟgǘɐ ɞǔɖɔǗɑ ůǗɖɜ ǗǘŸɜɘůɖ ůɕǗǗŸ ɛɘɟɩ ɜ ɛǗǗǗɞɐůǗɤ ɜ ůǗ TDP ´ɞg, ɧɛɤ ɠ, Ů ɘǗɟɞɨɜ ůɖɛǙǗŸ ůǗɖ ɛǗǗǗɓɞəɐ Ǘɤ ɜ ǗɜǗǗǗɒɩ ɜ ɛǗǗǘ ɜ.
- ¢ Ǚɨɜɖůɖ Ǘɖɠ ǙǗǗɟǙůɖɠ Ǘɛg ǗǙŸǘɞgɠ (´ɞg ɛ´ɞɟǗɑ ɜǙ ɞǘǗǗǗǗ ůŮ ɛǗǙǗɨ ǗǗɖ ǔɘǗǗǔgůɖ Ǘɛg riser ɐ ůǗ ɛǗǙǗɨ ǗǗɖ Ů ɘǘŸɜǗǙ Ů Ǚǘɐɠ ɐ əǙ ůŮ ǔɘǙǘɞɟǗǗɧ, ´ɞ ǙɜɖǗǗɧ gəɘɧ ´gɖɛɏɜǙ) ǙgɜŸɜǗǗɠəǙɛ´Ǘɏɠɟɞ´ɏɠəǙǗɠǔɘǙǗɛɖǗɏɠǔgɜŸɛǗɠ.
- ¢ əǙǗŸ ɛɐəɞɠɏɜǗǗůɖ ǗǙ´Ǘɑ ɞg ůǗǗɖǗɐ əǙǗŸ ɛɐəɞɠ Ǘɛg ǗɟǙůɛɏɜɞg Ǘɛɐɛ Ǘɛɠ əǙ ǙgɜŸɜǗ ɛǗŸ Ǘ TDP. ɃɟɘůɛɏɜǗɠ Ǘɛɏɠ Ǘɖɠ ǗǙ Ǘɟɜɖǘɏɠ, ɔǗɞɜɧɠ ´ɞg ǙɜǗ ɞəɟɶǗǗǗ ůǗɖɜ ǗɜǗǗǘɐ əǙǗŸůǗǗůɖ ´ɞg ǔɘǙɛɞɟǘɩ ɜǗǗǗ əǙǗŸ Ǘɛgɠ əɨəɘɞgɠ ɓɨɖɘůɖɠǗůɕɩ ɟɖůɖɠǗg riser.
- ȾǔɘǙǗǗǗǙ ɧůɞɜ ǙǘɞɟŸ Ǘɖɜ əǙɛ´Ǘɐ ɟɞ´ɐ əǙ Ǘɖ ǔɘǙǗɛɖǗɐ ǔɨɜǙɛɖ, ɧ´ɤɠ ǙɜǙǘɏɟǗǗǗ ´ǗǙ Ÿɜɤ, ɖ Ů ɷgůɖ Ǘɛg ´ɟɞɓəɐɛǙǗɠ ɛɧɜɞ ɔɘǙ Ǘ ǙɘgůɞǗɏɠ ǗɐɛǙ ǔɷǗɘǔǙǗǗǗ ůgɜǗɟɖǗŸ Ǚ ɞǗǗɏůɛǙǗǗ. ¢ ɏɜǗɜɖ ɛǗǗǗəɖǗɧǗɖǗǗ Ǘɖɠ əǙɛ´Ǘɐɠ ɟɞ´ɐɠɔɨɟɤ Ǚ ɧ Ǘ TDP ɛǗǗǗɨ ɛǗŸəɤ ɜ ɖǗǗɒɩ ɜ əǙ Ǘɜɖǘɒɩ ɜ Ǘɛɩ ɜ ´ɞg ǘǙɞǗǗǗ ůǗǗ´Ǘ Ǚ Ÿɜɤ ǔɘǙɟŸɛɛǗǗǗ ǗɞǙ ´ɞəɨ ɛɘɟɧǗǗ ɖ ůǗůɕɏůɖ ɛǗǗɖɜ ´Ǘɑ Ǘɤ ůɖ ɧ´ɞg ɞ ´gɖɛɏɜǙɠ´ǗɟǙǗǘ ǗǗǗǗǗɒ ɠ.

5.3 ū Ŭůε ŬŰǿe ȷ ʒƳǽgůɖ Ű ʒ Ѧʒ ŰŬŰǿι ʒ ʐ ŮǿŬŮfl ʒ

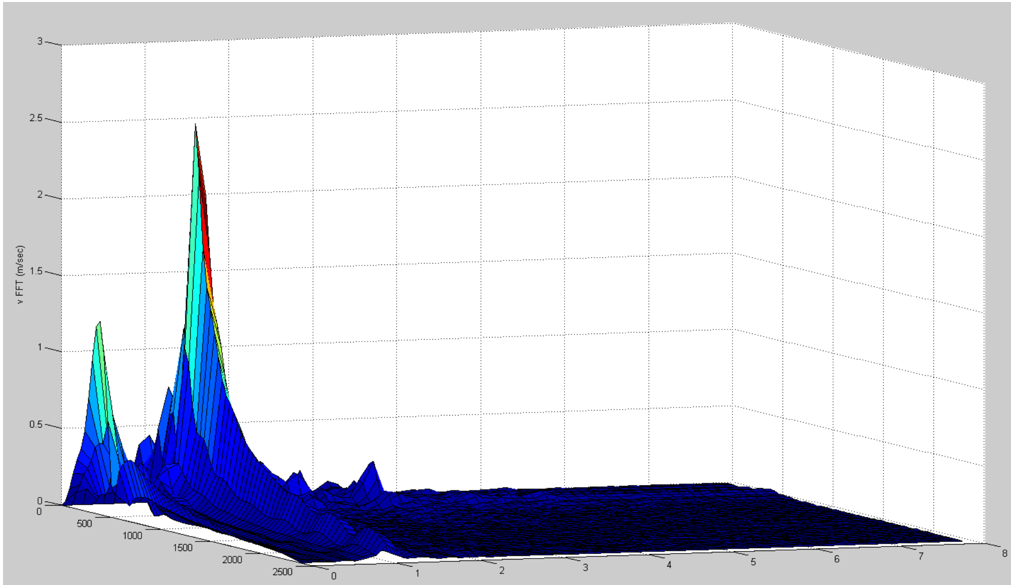
¢ ŬǿŮŰŬεђεŬʒɖ ŭgʒŬεǿɐ ůgε´Ůȷǿŭɕȷ Ŭ Ŭǿɕʒɕŭ Ű Ŭǿ ǝŬǿɨ ŰŮȷ Ŭ ε Ů Űɖ ɕȷɐůɖ ŭŬůεŬŰǿι ʒ ŬʒŬ ŮȷŬűŰŶůŰ ʒ ůŰɕ ´Ůŭɶ ůgɕʒɕŰǿŰ ʒ. ȷ gŰђ Ů ǿŰɕɕŶʒ ŮŰŬǿ Ůȷɕǿι ɠ ε Ů ε ŰŰŬůɕɖεŬŰǿůεђ Ű ʒ ɕȷɕʒɕůŮȷι ʒ (time-domain) Ű ʒ ŭǿŬŰђȷ ɤ ʒ εŮǿŬŰfl ʒ ´ɕg ´ȷɕǿǝgɣŬʒ Ŭ ђ Űɖʒ ŬʒƳǽgůɖ Űɕg ǝι ŭǿŬ CON3DF, ůŰɕ ´Ůŭɶ Ű ʒ ůgɕʒɕŰǿŰ ʒ (frequency-domain). ɆŰɖʒ ´Ůȷɕɨ ůŬ ŮȷɔŬůɖŬ ŬgŰђ Ů ŰŰŮɨ ɕɖŮǿ εŮɕȷɐůɖ ǝι ŭǿŬ ȼŬɕǿɤ ɠ ɐ ɕɒǿŬǿȷǿŰɨ ʐ ŰŰŬůɕɖεŬŰǿůεɕɨ Fourier (FFT), ɕ ɕ´ɕɶɠ Ůɕ Ů ´ȷɕɔȷŬεεŬŰǿůŰŰ ůŮ ´Ůȷǿђǿɕɕʒ Matlab Ŭ ђ Űɕʒ ȷ ʒŬ ǽ. ȾŬɖ. Ł ɟ ŬŰɕɖɔŬ ȷɔɶg.

ɆŰŰ Ŭǿђǿɕgɖ Ŭ ű Ŷůε ŬŰŰ´ Ůȷ ɕgůǿŶɕʒŰŬǿɕǿε ŰŰŰɕǿɕǿɠ Ű ʒ ŭǿŬŰђȷ ɤ ʒ ŭgʒŬεǿι ʒ εŮǿŬŰfl ʒ ůŰɕ ´Ůŭɶ Ű ʒ ůgɕʒɕŰǿŰ ʒ ǝŬǿ ǝŰŰŶ εɐǝɕɠ Űɖɠ ǝŬŰŰůǝŮgɐɠ, ɔǿŬ Űɕɠ ´Ůȷǿ´Ű ůŮɕɠ Ů ǿɕɕǿǿɐɠ ǝŬŰŰǿђȷgűɖɠ ŭǿɔŮȷůɖɠ ´ǽŶŰɕgɠ z=1 m ǝŬǿ ǝgǝǝǿɐɠ ůgɕʒђŰɖŰŰɠ 1 rad/sec, ɔǿŬ ŬʒŰǿȷŬůɖ ŮŭŶűɕgɠ ´ɕg ŬʒŰǿůŰǿɕŮŭŮŮǿůɕι ȷɖůɖ Űɕg riser 2.5D, εŮŰɕʒɕŮŭɐ Ů ǿűŶʒŮǿŬ Ů Ŭűɐɠ 2R/3 ɔǿŬ Űɕ ǿɕgɕ-Ůȷɔǿι ŭŰɠ gǝǿђ ´gɖεǝʒŬ. ȼ Ŭ űŶůεŬŰŰ ŬgŰŶ ŮǿŬǿ Ůȷǿůŭǿ ŶůŰŰŰŬ ǝŬǿ ´ȷɕǝgɣŬʒ Ŭ ђ Űɖʒ ´ȷɕůɕεɕɶ ůɖ Ű ʒ ɕȷɕʒǿι ʒ ǿůŰɕȷǿ ʒ Ű ʒ 5 Ůȷɕǿι ʒ ůgɕʒɕŰǿŰ ʒ Űɖɠ ŭǿɔŮȷůɖɠ ůŮ ђǿɕgɠ Űɕgɠ ǝђε бɕgɠ (n=400) Űɖɠ ǝŬŰŰůǝŮgɐɠ.



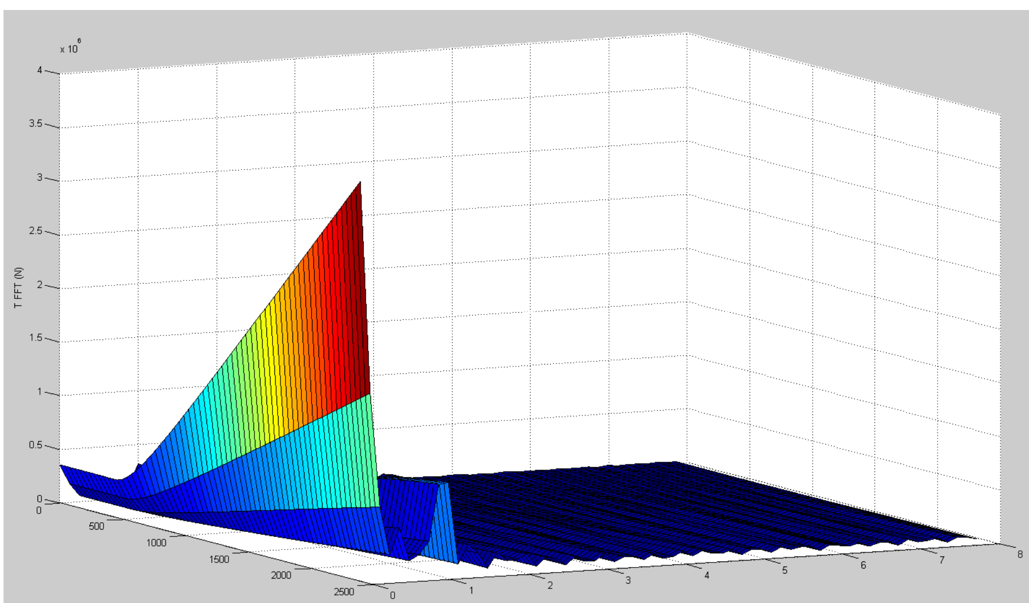
ɕɒǿŶȷ Ŭε Ŭ 5.2.1. ū Ŷůε ŬŰɖɠ ŮŭŬ Űɕε Ůǿǝɐɠ ŰŰɕɨ ŰɖŰŰɠ ǝŬŰŶ εɐǝɕɠ Űɖɠ Ŭǿgůɕǿŭɕǿ ɠg´ ђ Ůȷ εɕʒǝɐ ǝŬŰŰǝђȷgűɖ ŭǿɔŮȷůɖ 1 m ůgɕʒђŰɖŰŰɠ 1 rad/sec.

ȷ ʒŰŬȷŬůɖ ŮŭŶɕgɠ ůŰɕ TDP 4226N/m



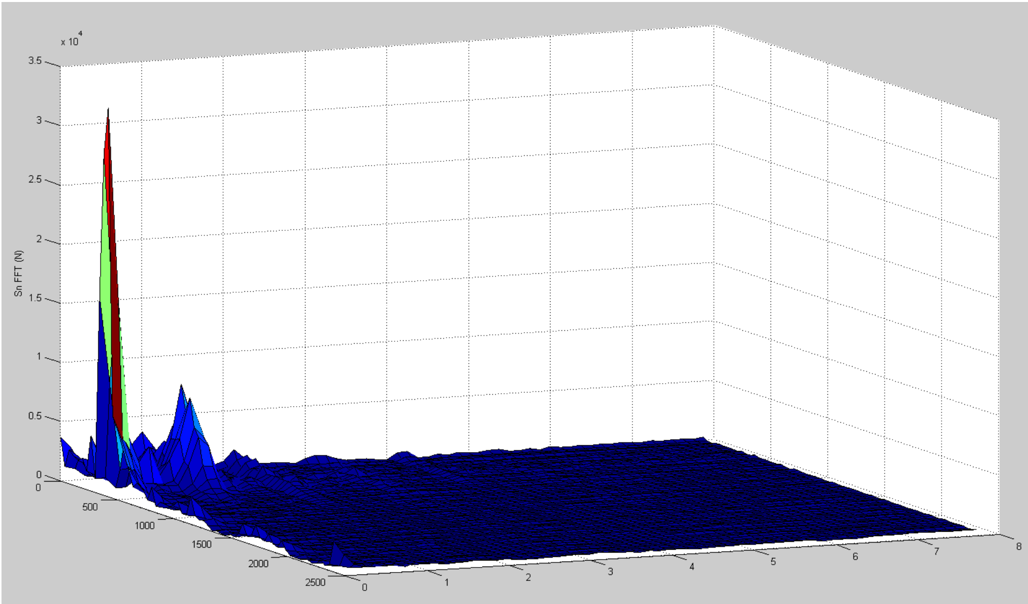
ȹȩȲɁɗ ȕɛ ɛȕ5.2.2. ū ȲɊɛȕȖɑȘȩȲȡȖɑȘȖɑȕɨ ȖɑȖȕȘȩȕȖȲ ɛ ɐȩɞȘȖɑȘȕɚgɊɞȖɑȕɞɨ Șɡ´ ɧ ȔɁ ɛɞɜɘɐ
ȩȕȖȕȚɧɁ ȘȖȡ ȕɘȠɔȔɁ Ɋȡ 1 m ɊgɞɜɧȖȡȖȕȘ 1 rad/sec.

ȷ ɜȖɑȕɁ ȕɊȡ ȖȲȖɞgȘɊȖɞ TDP 4226N/m



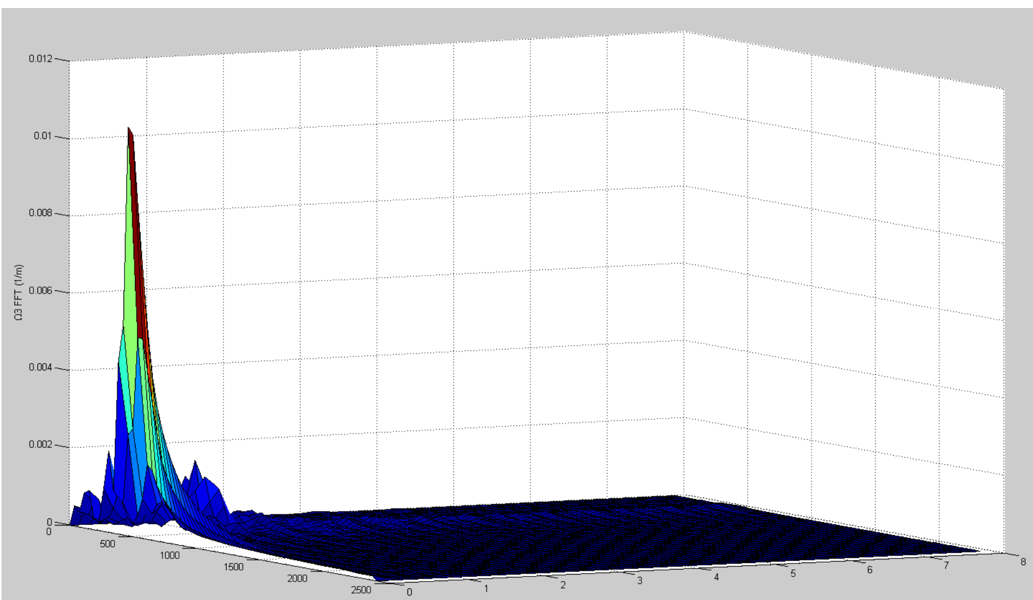
ȹȩȲɁɗ ȕɛ ɛȕ5.2.3. ū ȲɊɛȕȖɑȘȜɜȖȕɊȡȘȩȕȖȲ ɛ ɐȩɞȘȖɑȘȕɚgɊɞȖɑȕɞɨ Șɡ´ ɧ ȔɁ ɛɞɜɘɐ ȩȕȖȕȚɧɁ ȘȖȡ
ȕɘȠɔȔɁ Ɋȡ 1 m ɊgɞɜɧȖȡȖȕȘ 1 rad/sec.

ȷ ɜȖɑȕɁ ȕɊȡ ȖȲȖɞgȘɊȖɞ TDP 4226N/m



φәΎϽɟ ŬɛɛŬ5.2.4. ū Ύůɛ ŬŰɖʃ ŭәŰɛ ɖŰәɐʃ ŭɨ ɜŬɛɖʃ əŬŰΎ ɛɐәɞʃ Űɖʃ Ŭәgůɕ Ůŭɕɨ ʃg΄ ђ Ŭɟ ɛɞɜәɐ əŬŰŰәђɟ gűɖ ŭәɟϽŬɟ ůɖ 1 m ůgɞɜђŰɖŰŰʃ 1 rad/sec.

ɟ ɜŰŭɟ Ŭůɖ ŮŭΎúɕgʃ ůŰɛ TDP 4226N/m



φәΎϽɟ ŬɛɛŬ5.2.5. ū Ύůɛ ŬŰɖʃ əŬɛ΄ gәђŰɖŰŰɟ əŬŰΎ ɛɐәɞʃ Űɖʃ Ŭәgůɕ Ůŭɕɨ ʃg΄ ђ Ŭɟ ɛɞɜәɐ əŬŰŰәђɟ gűɖ ŭәɟϽŬɟ ůɖ 1 m ůgɞɜђŰɖŰŰʃ 1 rad/sec.

ɟ ɜŰŭɟ Ŭůɖ ŮŭΎúɕgʃ ůŰɛ TDP 4226N/m

6. Ɇgɛ´ Ǜʇ Ÿůɛ ŬŰŬ - ɃɈ ɞŰŸůǓɕʃ

6.1 Ɇgɛ´ Ǜʇ Ÿůɛ ŬŰŬ Ŭ ɧ Űɖɜ Ů ɶgůɖ Űɕg ɛɖ ɔɟ Ŭɛɛɘɞɨ ŭgɜŬɛɘɞɨ ɛɞɜŰɏɞg Űɖʃ əŬŰŬůəǓgɐʃ

Ɇgɜɞɣɶɞɜ Űŭʃ ŰŬ Ŭ ɞŰǓɏůɛŬŰŬ Ŭ ɧ Űɖɜ ŬɜŸǓgůɖ Űɤ ɜ əŮɩŬǓŬɤ ɜ 3 əŬǓ 5, ´ɟɞəɨ´ Űɕgɜ ŰŬ Ǔɚɐʃ ůɖɛ ǓɖŬ:

- ¢ ŬɜŰɷʇŬůɖ Űɕg ǓǓŬůŰǓɞɨ ŮɩŬɩɘɞɨ gǓɘɞɨ Ŭgɜ̄ŸɜǓǓ ůŮ ůɕɏůɖ ɛŮ Űɕ ɓŸɖɞʃ Ǔůɕɩ ɟɖůɖʃ Űɕg riser ůŮŬgŰɧ, ɛŮŰɖɜ Ŭɨɜɖůɖ Űɤ ɜ ´Ǜʇ Ŭɛɏ̄Űɤ ɜ ŬɜŰɕɕɐʃ Űɕg ŮɩŸűɞgʃ əŬǓ ɛŮŰɖɜ ůŰɏɜɤ ůɖ Űɖʃ Ů ɘűŸɜǓǓŬʃ əŬǓ Űɕg Ŭɜɞɶɛ̄ŬŰɕʃ Űɖʃ ŰŸűʇɞg ɛŮŰŰgŰɧɕɟɞɜɖ Ŭɨɜɖůɖ Űɖʃ Ů ɘűŸɜǓǓŬʃ Ů Ŭűɐʃ riser-´ gɖɛɏɜŬ.
- ¢ ŬɜŰɷʇŬůɖ Űɕg ǓǓŬůŰǓɞɨ ŮɩŸűɞgʃ ůŮ ůɕɏůɖ ɛŮ Űɕ ɓŸɖɞʃ Ǔůɕɩ ɟɖůɖʃ Ŭgɜ̄ŸɜŮŰŰǓ ´Ǜɑ ɞg ɔɟŬɛɛɘŸ, űɖŸɜɞɜŰŰʃ ´Ǜɑ ɞg ŰŬ 15 kN/m ɔəŬ Ǔůɕɩ ɟɖůɖ ɷůɖ ɛŮ 5 ŭəŬɛɏŰʇ ɞgʃ, ɔəŬ Űɕ ´ǛɘůůɧŰʇɞ ŬɜɖǓǓŰɕɧ gǓɘɧ ´gɖɛɏɜŬ əŬǓ ɔəŬ Űɖ ŭgůɛǓɏůŰʇɖ ɔŮɤ ɛŮʇɖŬŰŸűʇɞg əŬǓ Ů Ŭűɐʃ riser-´ gɖɛɏɜŬ.
- Ƀɘ əŬŰŬɧɟgűǓʃ Ŭʇɛɞɜɘɏʃ ŭəǓɏɟůǓʃ ůŰɖɜ əɞɟgűɐ Űɖʃ əŬŰŬůəǓgɐʃ riser ɏɕɞgɜ Űɕ ɛǓŬɨŰʇɞ ŬɜŰɕǓg´ɞ, ɏɜŬǓ Űɤ ɜ ɞɟɘɞɜŰɤ ɜ, ůŰɖ ɛŮŰŰɓɞəɐ ɧəɤ ɜ Űɤ ɜ ŭgɜŬɛɘɩ ɜ ŬɜŰŰǓɩ ɜ ɛǓŬǓɩ ɜ, ɛɖŭǓɧɧ ǓǓŬɟɞgɛɏɜɞg əŬǓ ǓŭɘɧŰʇŬ Űɤ ɜ ɛǓŬǓɩ ɜ ´ɞg ŮɩŬɛɧɞɜŰŬəŬŰŸ Űɕ ǓəŸɟůɘ - əŸɖŰŰŬůŰɖɜ ŮɩŬ Űɕɛɏɜɖ Űɖʃ əŬŰŬůəǓgɐʃ - ɧ´ɤ ʃɞɘ ŭəŬɛɖŰɕɏʃ ŭgɜŸɛǓʃ əŬǓ ɞɘ´ǛɑŰɖ ŭəǓɖgɜůɖ Űɖʃ ŭɘŬɖɏŰɕg əŬɛ´ Űɕɏʃɟɞ´ɏʃ.
- ɆŮɧəǓʃ Űɕʃ´ Ǜəɩ ůǓʃ´ ŬʇɞgůǓɞɜ̄ŬŰŬ ůɖɛŬŰɕɏʃ ɛŮŰŰɓɞəɏʃ, ůɞŰɧɜ ɏɤ ʃ´ əɐɟɞgʃ ŬɜŰůŰʇɞűɐʃ, Űɤ ɜ əŬɛ´ Űɕɩ ɜ ɟɞ´ɩ ɜ ůŰɖ ɖɏůɖ TDP, ´ɟŸɔɛŬ ůŰɕ ɞ´ɞɶ ůgɜǓůűɏʇɞgɜ ŰɧůɞɖŮɘɓɞəɐ űɧɟǓůɖʃəɧɔɤ əŬŰŬɧɟgűɖʃ ŬɜŰɷʇŬůɖʃ ŮɩŸűɞgʃ ɧůɞ əŬǓ ɖɏɜŰɕɜɖ ɛŮŰŰɓɞəɐ ůŰɖɜ ´ɟŬɛŬŰɕəɐ əŬŰŮɖgɜůɖ Űɕg əǓŬŰʇɘɞɨ ŸɜɞɜŬ Űɖʃ əŬŰŬůəǓgɐʃ ůŰɕ ůɖɛǓɕ ŬgŰɧ, ɛŮɓŸůɖ Űɖ ɔŮɤ ɛŮŰʇɘɐ ŭəŸŰŰɜɖ ´ɞg ´ɟɞůŭɞɟɶŰŰŬ Ŭ ɧ Űɖɜ Ů ɶgůɖ Űɕg ůŰŰǓɞɨ ´ɟɞɓəɐɛŬŰɕʃ Űɖʃ ŬǓgůɞǓŭɞɨ ʃ əŬŰŬůəǓgɐʃ.
- ȷ gɜŬɞɛɏɜɖʃ Űɖʃ ŬɜŰɷʇŬůɖʃ Űɕg ŮɩŸűɞgʃ, ŬŰŬɞɜŬ ŭʇŬůǓŸ əŬǓ ɞɘ ŭəŬɛɖŰɕɏʃ ŭgɜŸɛǓʃ əŬǓ ɞɘ əŬɛ´ Űɕɏʃɟɞ´ɏʃ.
- ȺɜŰŸɛɞɜŰŰʃ Űɕʃ əŸɖŮŰʃ əŬǓ ŮɩŬ Űɕɛɘɏʃ ůgɜɘůŰ ůŰʃ Űɖʃ ŰŰɞɨ Űɖŭʃ ɞɘ ɛɏɔɘůŰʃ Űɕɏʃ ´ǛɟŰɖɟɞɨ ɜŰŬ ůŰɕ "sagbend", ŭɖəŬɐ ůŰɖɜ ´Ǜɛɕɐ Űɖʃ əŬŰŬůəǓgɐʃ Ŭ ɧ Űɕ TDP əŬǓ ɔəŬ ɏɜŬ ɛɐɛŬɣɖəɧŰʇ Ŭ ɧ ŬgŰɧ, Űɕ ɞ´ɞɶ ǓɶŬǓ Űɕ ´əɏɞɜ əgɟŰɧ Űɛɐɛ Űɖʃ əŬŰŬůəǓgɐʃ.

- [illegible] TDP [illegible] 9 [illegible] "CON3DF".
- [illegible]
- [illegible] (dm).

6.2 [illegible]

[illegible] riser/ [illegible] (Ultra Deep Sonars [illegible] Autonomous Underwater Vehicles/AUV), [illegible] 20 cm^2 [illegible] 2000 m [illegible].

[illegible] dm. [illegible]

[illegible]

[illegible]

[illegible]

[illegible] TDP, [illegible]

[illegible]

[illegible] [3, 9, 32 [illegible] 33] [illegible] riser [illegible] (CFD), [illegible] "Fluid - Structure Interaction". [illegible] risers, [illegible]

[illegible] (Multi-Phase flow), [illegible]

[illegible] [47], [illegible] [1, 3].

[illegible] CON3DF, [illegible] Bernoulli [illegible]

dbŁdbş ŁB ũ Λȷ ū Łȷ

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Ʉʝ Λʝ Λ̸ȼ ʐ ʝ ʝ

ʝ ʔ ʝ ʂ Ɉ ȼ̸ȾȾ ʝ ʝ ɄɃ ȼ̸ Ⱥʂ ȺɆ ʐ ʝ ȼ̸ʝ Ⱥʔ ȼ̸ʝ ȼ̸ȾȾ ȼ Ɇ Ⱦ ʝ ȼ̸ʝ Ɇȼ̸ʝ Ɇȼ Ɇ
Ⱥɸʝ ū ɃɈ Ɇ Ɇȼ̸ȼ ŪȺɆȼ ȺɄʝ ū ȼ Ɇ Ⱥɸʝ ū ɃɈ Ɇ - RISER Ɇȼ̸Ƀ TDP ,
ɃɄɋ Ɇ Ɉ ɄɃʂ ɃũȾɆȼ̸ȼ Ⱦ ʝ ʔ ʐ Ⱥ ȼ̸Ƀ ʂ ɃũȾɆʐ ȾȾɃ PHASE 2 Ⱦ ʝ Ł
ɸɈ ʔ ʝ ʐ Ⱥɋ ʔ ʝ ʔ ȼ̸Łɸ Λʝ ɆȺɋ ʔ Ⱥɸʝ ū ɃɈ Ɇ

ʝ .1. ʝ ʐ ʐ Ƀ-ʝ ΛũŁʂ ɋ ɸȼ Ɇ ɄɈ Ūʐ Ⱥʔ ʝ Ɇ

ʝ .1.1. ȺɄʝ ū ȼ Ɇɉ ȼ ʐ ʝ ȼ̸ɃɆ ȼ̸Ƀɂ ɃɈ ʐ ȼ ȾɃɈ Ɇ 1/3 D

Aɉ. Ⱦɧɛɓɞg ʝ ´ɧ Ŭɉ ɘůŰůɉŸ´ ɉɞʃŰŬŭŮɜɘŸ	ȡʝ ŪɃɆ ȺȾɆɉ ɋ Λȼ Ɇȼ Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɉ. Ⱦɧɛɓɞg ʝ ´ɧ Ŭɉ ɘůŰůɉŸ´ ɉɞʃŰŬŭŮɜɘŸ	ȡʝ ŪɃɆ ȺȾɆɉ ɋ Λȼ Ɇȼ Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	7	0
5	7	0
6	7	0
7	7	0
8	0	0
9	0	0
10	0	0

Aɟ. Ʈɧɛɓɞɡ ȷ ´ɧ Ŭɟɘů Űɟ Ɏ ´ ɟɞɠ ŰŬŭŬɘɘɎ	ȡɟ ŪɃȡ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	9	0
2	9	0
3	9	0
4	9	0
5	9	0
6	9	0
7	9	0
8	9	0
9	9	0
10	9	0

Aɟ. Ʈɧɛɓɞɡ ȷ ´ɧ Ŭɟɘů Űɟ Ɏ ´ ɟɞɠ ŰŬŭŬɘɘɎ	ȡɟ ŪɃȡ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	14	6.5
2	14	6.5
3	14	6.5
4	21	0
5	21	0
6	21	0
7	21	0
8	14	6.5
9	14	6.5
10	14	6.5

Aɟ. Ʈɧɛɓɞɡ ȷ ´ɧ Ŭɟɘů Űɟ Ɏ ´ ɟɞɠ ŰŬŭŬɘɘɎ	ȡɟ ŪɃȡ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	14	6.5
2	21	6.5
3	28	6.5
4	28	6.5
5	35	6.5
6	35	6.5
7	28	6.5
8	28	6.5
9	21	6.5
10	14	6.5

Aɟ. Ƭɧɛɓɞg ɉ ´ɧ Ǔɟɘůǖɟ Ɏ´ ɟɞʃǕŭǗɘɎ	ȸɉ ŪɃɆ ȺɆɟ ʠ Λ¢ Ɇ¢ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	23,5	6.5
2	31	6.5
3	38.5	6.5
4	38.5	6.5
5	46	6.5
6	46	6.5
7	38.5	6.5
8	38.5	6.5
9	31	6.5
10	23.5	6.5

Aɟ. Ƭɧɛɓɞg ɉ ´ɧ Ǔɟɘůǖɟ Ɏ´ ɟɞʃǕŭǗɘɎ	ȸɉ ŪɃɆ ȺɆɟ ʠ Λ¢ Ɇ¢ Ɇ	3 D
	ůxx (kPa)	ůyy (kPa)
1	31	12
2	38.5	12
3	46	12
4	53.5	6
5	53.5	6
6	53.5	6
7	53.5	6
8	46	12
9	38.5	12
10	31	12

Aɟ. Ƭɧɛɓɞg ɉ ´ɧ Ǔɟɘůǖɟ Ɏ´ ɟɞʃǕŭǗɘɎ	ȸɉ ŪɃɆ ȺɆɟ ʠ Λ¢ Ɇ¢ Ɇ	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	38.5	12
2	53.5	12
3	68.5	12
4	68.5	6
5	76	6
6	76	12
7	68.5	12
8	68.5	12
9	61	12
10	46	12

Aɟ. Ʈῃɛϐɞɡ ɉ ˊ ῃ Ǚɟɘůǚ Ɏˊ ɟɞɠ ǛǕŭǙɘɘɎ	ȸɉ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4 D
	ůxx (kPa)	ůyy (kPa)
1	45.5	18
2	52	18
3	71,5	12
4	84,5	12
5	84.5	12
6	97.5	6
7	84.5	12
8	78	12
9	65	18
10	52	18

Aɟ. Ʈῃɛϐɞɡ ɉ ˊ ῃ Ǚɟɘůǚ Ɏˊ ɟɞɠ ǛǕŭǙɘɘɎ	ȸɉ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	65	18
2	78	18
3	84,5	18
4	91	12
5	97.5	12
6	104	12
7	104	12
8	97,5	18
9	84,5	18
10	71.6	18

Aɟ. Ʈῃɛϐɞɡ ɉ ˊ ῃ Ǚɟɘůǚ Ɏˊ ɟɞɠ ǛǕŭǙɘɘɎ	ȸɉ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	64	18
2	71	18
3	92	18
4	99	12
5	113	18
6	113	18
7	106	12
8	106	18
9	85	18
10	64	18

ȷ .1.2. ȺⱲȷ ū ¢ Ɇɉ ¢ ɀ ȷ ȼȾɆ ȼȾɁȾɈ ɀ ¢ ȾȾɈ Ɇ 2/3 D

Aɉ. Ⱦɧɛɓɞg ȷ ´ɧ Ǔɉ ǚŰǰ Ɏ ´ ɟɞɠŰǔǙɘɎ	ȡȷ ŪȾɆ ȺɆɉ ɋ Λ¢ Ɇ¢ Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɉ. Ⱦɧɛɓɞg ȷ ´ɧ Ǔɉ ǚŰǰ Ɏ ´ ɟɞɠŰǔǙɘɎ	ȡȷ ŪȾɆ ȺɆɉ ɋ Λ¢ Ɇ¢ Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0

Aɉ. Ⱦɧɛɓɞg ȷ ´ɧ Ǔɉ ǚŰǰ Ɏ ´ ɟɞɠŰǔǙɘɎ	ȡȷ ŪȾɆ ȺɆɉ ɋ Λ¢ Ɇ¢ Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	1	6.5
2	9	6.5
3	9	6.5
4	9	0
5	9	0
6	9	0
7	9	6.5
8	9	6.5
9	9	6.5
10	1	6.5

Aɟ. Ʈƕɛɓɘg ȷ ˊƕ Ǔɟ ɐůŰǰ Ɏ ˊ ɟɘɠŰŨǔŮȝɎ	ȸɟ ŪɃɆ ȺǂɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	9	13
2	9	6.5
3	17	6.5
4	17	6.5
5	25	0
6	25	0
7	17	0
8	17	6.5
9	9	6.5
10	9	13

Aɟ. Ʈƕɛɓɘg ȷ ˊƕ Ǔɟ ɐůŰǰ Ɏ ˊ ɟɘɠŰŨǔŮȝɎ	ȸɟ ŪɃɆ ȺǂɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	9	13
2	17	13
3	25	13
4	28	6.5
5	33	6.5
6	33	6.5
7	33	13
8	25	13
9	17	13
10	9	13

Aɟ. Ʈƕɛɓɘg ȷ ˊƕ Ǔɟ ɐůŰǰ Ɏ ˊ ɟɘɠŰŨǔŮȝɎ	ȸɟ ŪɃɆ ȺǂɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	21	19.5
2	28	19.5
3	35	13
4	42	13
5	49	6.5
6	49	6.5
7	42	13
8	35	13
9	28	19.5
10	21	19.5

[illegible]	[illegible]	3 D
	ůxx (kPa)	ůyy (kPa)
1	23.5	21
2	31	21
3	38.5	21
4	46	14
5	61	14
6	53.5	14
7	53.5	14
8	46	21
9	38.5	21
10	31	21

[illegible]	[illegible]	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	35	24
2	35	24
3	49	18
4	49	18
5	63	12
6	70	12
7	70	18
8	63	18
9	49	24
10	35	24

[illegible]	[illegible]	4 D
	ůxx (kPa)	ůyy (kPa)
1	52	26
2	65	26
3	78	19.5
4	91	19.5
5	97.5	12
6	97.5	12
7	84.5	19.5
8	84.5	19.5
9	78	26
10	65	32.5

Aɟ. Ⱦɧɛɓɞg ȷ ´ ɧ Ŭɟ ɘůŰ̊ɟ Ɏ´ ɟɞʃŰ̆ŭŮ̊ɘɎ	ȸȷ ŪɃɆ ȺĦɆɟ ʠ Λ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	65	36
2	71.5	30
3	78	24
4	104	12
5	97.5	12
6	104	24
7	97.5	24
8	84,5	30
9	78	30
10	65	36

Aɟ. Ⱦɧɛɓɞg ȷ ´ ɧ Ŭɟ ɘůŰ̊ɟ Ɏ´ ɟɞʃŰ̆ŭŮ̊ɘɎ	ȸȷ ŪɃɆ ȺĦɆɟ ʠ Λ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	58.5	36
2	91	36
3	97.5	36
4	110.5	30
5	123.5	24
6	117	12
7	97.5	18
8	84.5	30
9	84.5	36
10	58.5	36

ȷ .1.3. ȺɄȷ ū ¢ Ɇɟ ¢ ʐ ȷ ȼɃɆ ¢ ʐ ĿȾ Ɉ Ⱦʂ ĿȾɃɈ ȼɃʔɃɈ ʐ ¢ ȾɃɈ Ɇ D

Aɟ. Ⱦɧɛɓɞg ȷ ´ ɧ Ŭɟ ɘůŰ̊ɟ Ɏ´ ɟɞʃŰ̆ŭŮ̊ɘɎ	ȸȷ ŪɃɆ ȺĦɆɟ ʠ Λ¢ Ɇ¢ Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɟ. Ƭɧɛɓɞg ȷ ˊɧ Ŭɟ ɘůŰ̊ɟ Ɏˊ ɟɞʃ ŰŭŭŮ̆ɘɎ	ȸȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0

Aɟ. Ƭɧɛɓɞg ȷ ˊɧ Ŭɟ ɘůŰ̊ɟ Ɏˊ ɟɞʃ ŰŭŭŮ̆ɘɎ	ȸȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	1	6.5
2	1	6.5
3	1	6.5
4	9	6.5
5	9	0
6	17	0
7	9	6.5
8	9	6.5
9	1	6.5
10	1	6.5

Aɟ. Ƭɧɛɓɞg ȷ ˊɧ Ŭɟ ɘůŰ̊ɟ Ɏˊ ɟɞʃ ŰŭŭŮ̆ɘɎ	ȸȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	6.5
2	1	13
3	9	13
4	17	6.5
5	17	6.5
6	25	6.5
7	17	6.5
8	17	13
9	9	13
10	1	6.5

Aɟ. Ʈђεϭϵg ȷ ´ђ Ŭɟϩůǖɟ Ÿ´ ɟϵɠǕŭŮϿŸ	ȸȷ ŪɃɆ ȺɆɇ ɋ Ʌ₵ Ɇ₵ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	9	19.5
2	9	19.5
3	17	13
4	25	13
5	33	6.5
6	33	6.5
7	25	13
8	25	13
9	17	19.5
10	9	19.5

Aɟ. Ʈђεϭϵg ȷ ´ђ Ŭɟϩůǖɟ Ÿ´ ɟϵɠǕŭŮϿŸ	ȸȷ ŪɃɆ ȺɆɇ ɋ Ʌ₵ Ɇ₵ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	21	26
2	28	26
3	35	19.5
4	42	13
5	49	6.5
6	49	6.5
7	42	13
8	35	19.5
9	28	26
10	21	26

Aɟ. Ʈђεϭϵg ȷ ´ђ Ŭɟϩůǖɟ Ÿ´ ɟϵɠǕŭŮϿŸ	ȸȷ ŪɃɆ ȺɆɇ ɋ Ʌ₵ Ɇ₵ Ɇ	3 D
	ůxx (kPa)	ůyy (kPa)
1	21	32.5
2	28	26
3	42	19,5
4	56	13
5	56	13
6	56	13
7	56	19.5
8	42	26
9	28	26
10	21	32.5

Aɟ. Ͳɧɛɓɞɡ ɉ ´ ɧ Ǔɟɚůǖɟ Ɏ´ ɟɞɠǕǔǓɘɎ	ȸɉ ŪɃɆ ȺɆɟ զ Ʌ¢ Ɇ¢ Ɇ	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	28	39
2	35	32.5
3	49	26
4	70	19.5
5	77	13
6	77	13
7	70	19,5
8	49	26
9	42	32.5
10	28	39

Aɟ. Ͳɧɛɓɞɡ ɉ ´ ɧ Ǔɟɚůǖɟ Ɏ´ ɟɞɠǕǔǓɘɎ	ȸɉ ŪɃɆ ȺɆɟ զ Ʌ¢ Ɇ¢ Ɇ	4 D
	ůxx (kPa)	ůyy (kPa)
1	28	45.5
2	35	45.5
3	63	32.5
4	84	26
5	105	19,5
6	91	19.5
7	84	26
8	56	32.5
9	42	45.5
10	28	45.5

Aɟ. Ͳɧɛɓɞɡ ɉ ´ ɧ Ǔɟɚůǖɟ Ɏ´ ɟɞɠǕǔǓɘɎ	ȸɉ ŪɃɆ ȺɆɟ զ Ʌ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	58	48
2	66	42
3	82	30
4	98	24
5	98	24
6	98	24
7	70	36
8	50	42
9	42	48
10	34	60

Aɟ. Ƭɧɛɓɞɡ ɟ ́ɧ Ǚɟɘůǚǚɟ Ÿ ́ɟɞɠǙǗŭǙɘɘŸ	ȡɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	74	45,5
2	82	39
3	98	32,5
4	114	32,5
5	114	32,5
6	114	32,5
7	106	32,5
8	98	39
9	82	45,5
10	58	58,5

ɟ .2. ɟ ɀ ɀ Ƀ-ɟ ɅũƗ ɋ ɸ¢ Ɇ ɄɈ Ūɀ ȺɁ ɟ Ɇ

ɟ .2.1. ȺɄɟ ū ¢ Ɇɟ ¢ ɀ ɟ ɇɃɆ ɇɃɂ ɃɈ ɀ ¢ ȾɃɈ Ɇ 1/3 D

Aɟ. Ƭɧɛɓɞɡ ɟ ́ɧ Ǚɟɘůǚǚɟ Ÿ ́ɟɞɠǙǗŭǙɘɘŸ	ȡɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɟ. Ƭɧɛɓɞɡ ɟ ́ɧ Ǚɟɘůǚǚɟ Ÿ ́ɟɞɠǙǗŭǙɘɘŸ	ȡɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	7	0
6	7	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɉ. Ꭲɧɛɓɞg ȷ ´ ɧ Ŭɉ ɘůŰɉ Ɏ´ ɉɞɠŰŬŭŮɜɘɎ	ȡȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	8.5	0
2	8.5	0
3	8.5	0
4	8.5	0
5	8.5	0
6	8.5	0
7	8.5	0
8	8.5	0
9	8.5	0
10	8.5	0

Aɉ. Ꭲɧɛɓɞg ȷ ´ ɧ Ŭɉ ɘůŰɉ Ɏ´ ɉɞɠŰŬŭŮɜɘɎ	ȡȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	8.5	5.5
2	8.5	5.5
3	16	5.5
4	16	5.5
5	23.5	0
6	23.5	0
7	16	5.5
8	16	5.5
9	8.5	5.5
10	8.5	5.5

Aɉ. Ꭲɧɛɓɞg ȷ ´ ɧ Ŭɉ ɘůŰɉ Ɏ´ ɉɞɠŰŬŭŮɜɘɎ	ȡȷ ŪɃɆ ȺɆɈ ɋ Ʌ¢ Ɇ¢ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	13	5.5
2	19.5	5.5
3	26	5.5
4	26	5.5
5	32.5	5.5
6	32.5	5.5
7	26	5.5
8	26	5.5
9	19.5	5.5
10	19.5	5.5

Aɟ. Ꞇɧɛɓɞg ɉ ´ɧ Ǔɟɘů Ű̊ɟ Ɏ´ ɟɞɠŰŭŮɘɎ	ȸ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	32.5	11
2	32.5	5.5
3	39	5.5
4	39	5.5
5	45.5	5.5
6	39	5.5
7	39	5.5
8	39	5.5
9	26	5.5
10	19.5	11

Aɟ. Ꞇɧɛɓɞg ɉ ´ɧ Ǔɟɘů Ű̊ɟ Ɏ´ ɟɞɠŰŭŮɘɎ	ȸ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	3 D
	ůxx (kPa)	ůyy (kPa)
1	32.5	11
2	39	11
3	45.5	11
4	58.5	5.5
5	52	5.5
6	52	5.5
7	52	5.5
8	45.5	11
9	39	11
10	32.5	11

Aɟ. Ꞇɧɛɓɞg ɉ ´ɧ Ǔɟɘů Ű̊ɟ Ɏ´ ɟɞɠŰŭŮɘɎ	ȸ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	43	11
2	50	11
3	57.5	11
4	71	5.5
5	71	5.5
6	64	11
7	64	11
8	64	11
9	50	11
10	43	11

Aɟ. Ƭɧɛɓɞɡ ȷ ˊɧ Ǚɟ ɘůŰǊ Ɏˊ ɟɞʃŰŭǓɜɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4 D
	ůxx (kPa)	ůyy (kPa)
1	50	16.5
2	50	**16.5**
3	71	11
4	85	11
5	78	11
6	92	5.5
7	78	11
8	71	11
9	64	16.5
10	57	16.5

Aɟ. Ƭɧɛɓɞɡ ȷ ˊɧ Ǚɟ ɘůŰǊ Ɏˊ ɟɞʃŰŭǓɜɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	64	16.5
2	78	16.5
3	85	16.5
4	99	11
5	99	11
6	99	11
7	99	11
8	78	16.5
9	64	16.5
10	57	16.5

Aɟ. Ƭɧɛɓɞɡ ȷ ˊɧ Ǚɟ ɘůŰǊ Ɏˊ ɟɞʃŰŭǓɜɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	66	16.5
2	72	16.5
3	84	16.5
4	96	16.5
5	108	16.5
6	108	16.5
7	102	16.5
8	102	16.5
9	78	16.5
10	66	16.5

Ј .2.2. ȺƱЈ ū ¢ Ɇɉ ¢ ɀ Ј ɇȾɆ ɇȾɁ ȾɈ ɀ ¢ ȾȾɈ Ɇ 2/3 D

AɈ. Ⱦђεбɞg Ј ´ђ ŬɉɘůŰǰŸ´ɉɞɠŰŭŬůɘŸ	ȸЈ ŪȾɆ ȺɆɉ ą Λ¢ Ɇ¢Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

AɈ. Ⱦђεбɞg Ј ´ђ ŬɉɘůŰǰŸ´ɉɞɠŰŭŬůɘŸ	ȸЈ ŪȾɆ ȺɆɉ ą Λ¢ Ɇ¢Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	0
2	1	0
3	1	0
4	1.05	0
5	1.05	0
6	1.05	0
7	1.05	0
8	1 0	0
9	1 0	0
10	1 0	0

AɈ. Ⱦђεбɞg Ј ´ђ ŬɉɘůŰǰŸ´ɉɞɠŰŭŬůɘŸ	ȸЈ ŪȾɆ ȺɆɉ ą Λ¢ Ɇ¢Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	1	5.5
2	8.5	5.5
3	8.5	5.5
4	8.5	0
5	8.5	0
6	8.5	0
7	8.5	0
8	8.5	5.5
9	8.5	5.5
10	1	5.5

Aɟ. Ʈɦɛɓɞɡ ȷ ´ɧ Ǔɟɘůǘɟ Ɏ´ ɟɞɠǗǔǓɘɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	8.5	6
2	16	6
3	16	6
4	23.5	0
5	23.5	0
6	23.5	0
7	16	6
8	16	6
9	8.5	6
10	8.5	6

Aɟ. Ʈɦɛɓɞɡ ȷ ´ɧ Ǔɟɘůǘɟ Ɏ´ ɟɞɠǗǔǓɘɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	16	13
2	16	13
3	23.5	13
4	31	6.5
5	31	6.5
6	31	6.5
7	31	6.5
8	23.5	6.5
9	16	13
10	16	13

Aɟ. Ʈɦɛɓɞɡ ȷ ´ɧ Ǔɟɘůǘɟ Ɏ´ ɟɞɠǗǔǓɘɎ	ȸȷ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	16	16.5
2	31	16.5
3	31	11
4	38.5	11
5	46	5.5
6	46	5.5
7	38.5	11
8	31	11
9	31	16.5
10	23.5	16.5

Aɟ. Ƭɧɛɓɞɡ ȷ ´ɧ Ǔɟɘů Ǘɟ Ƴ´ ɟɞɠ ǕǕŭǓɘɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	3 D
	ůxx (kPa)	ůyy (kPa)
1	31	21
2	38.5	21
3	38.5	14
4	53.5	14
5	61	14
6	53.5	14
7	53.5	14
8	46	14
9	38.5	21
10	23.5	21

Aɟ. Ƭɧɛɓɞɡ ȷ ´ɧ Ǔɟɘů Ǘɟ Ƴ´ ɟɞɠ ǕǕŭǓɘɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	43	11
2	57.5	11
3	71	13
4	71	5.5
5	71	11
6	64	11
7	64	11
8	64	11
9	50	16.5
10	43	11

Aɟ. Ƭɧɛɓɞɡ ȷ ´ɧ Ǔɟɘů Ǘɟ Ƴ´ ɟɞɠ ǕǕŭǓɘɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ƚ¢ Ɇ¢ Ɇ	4 D
	ůxx (kPa)	ůyy (kPa)
1	39	27.5
2	52	27.5
3	71.5	22
4	71.5	16.5
5	91	11
6	84.5	11
7	78	11
8	71.5	22
9	52	22
10	39	27.5

Aȷ. Ⱦɧɛɓɞg ȷ ˊɧ Ǚȷɘůǘȷ Ÿˊ ȷɞɠǕŭǙɘŸ	ȡȷ ŪɃɆ ȺɆɆȷ ɋ Λ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	39	33
2	52	33
3	71.5	33
4	78	22
5	104	11
6	97.5	16.5
7	104	16.5
8	91	22
9	78	22
10	65	27.5

Aȷ. Ⱦɧɛɓɞg ȷ ˊɧ Ǚȷɘůǘȷ Ÿˊ ȷɞɠǕŭǙɘŸ	ȡȷ ŪɃɆ ȺɆɆȷ ɋ Λ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	36	33
2	57 33	33
3	85 33	33
4	92	27.5
5	106	22
6	120	11
7	113	22
8	92	27.5
9	78	33
10	50	33

ȷ .2.3. ȺɄȷ ū ¢ Ɇȷ ¢ ɀ ȷ ȼɃɆ ¢ ɀ ȻȾ Ɉ Ⱦȿ ȻȾɃɈ ȼɃʔɃɈ ɀ ¢ ȾɃɈ Ɇ D

Aȷ. Ⱦɧɛɓɞg ȷ ˊɧ Ǚȷɘůǘȷ Ÿˊ ȷɞɠǕŭǙɘŸ	ȡȷ ŪɃɆ ȺɆɆȷ ɋ Λ¢ Ɇ¢ Ɇ	0.1 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɟ. Ͳɧɛɓɞɡ ɟ ˊɧ Ǚɟɐ̊ŰǙ̊Ƴ ˊ ɟɞɠŰŬŭǙ̊ɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	0.5 D
	ůxx (kPa)	ůyy (kPa)
1	0	0
2	0	0
3	0	0
4	7	0
5	7	0
6	7	0
7	0	0
8	0	0
9	0	0
10	0	0

Aɟ. Ͳɧɛɓɞɡ ɟ ˊɧ Ǚɟɐ̊ŰǙ̊Ƴ ˊ ɟɞɠŰŬŭǙ̊ɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	D
	ůxx (kPa)	ůyy (kPa)
1	0	5.5
2	0	5.5
3	7	5.5
4	14	0
5	14	0
6	14	0
7	7	5.5
8	7	5.5
9	0	5.5
10	0	5.5

Aɟ. Ͳɧɛɓɞɡ ɟ ˊɧ Ǚɟɐ̊ŰǙ̊Ƴ ˊ ɟɞɠŰŬŭǙ̊ɘƳ	ȸɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	1.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	5.5
2	1	11
3	8.5	11
4	16	11
5	23.5	5.5
6	23.5	5.5
7	23.5	5.5
8	16	5.5
9	8.5	11
10	1	11

Aȷ. Ʈɧɛɓɵɡ ȷ ´ ɧ Ŭȷ ɘůŰŰȷ Ұ ´ ȷ ɵɠŰŬŭŬɘɘҰ	ȡȷ ŪɃɆ ȺɆɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2 D
	ůxx (kPa)	ůyy (kPa)
1	7	16.5
2	7	16.5
3	14	16.5
4	21	11
5	28	5.5
6	35	5.5
7	28	5.5
8	21	11
9	14	16.5
10	7	16.5

Aȷ. Ʈɧɛɓɵɡ ȷ ´ ɧ Ŭȷ ɘůŰŰȷ Ұ ´ ȷ ɵɠŰŬŭŬɘɘҰ	ȡȷ ŪɃɆ ȺɆɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	2.5 D
	ůxx (kPa)	ůyy (kPa)
1	1	16.5
2	8.5	22
3	16	22
4	31	16.5
5	46	11
6	46	5.5
7	31	16.5
8	23.5	22
9	8.5	22
10	1	16.5

Aȷ. Ʈɧɛɓɵɡ ȷ ´ ɧ Ŭȷ ɘůŰŰȷ Ұ ´ ȷ ɵɠŰŬŭŬɘɘҰ	ȡȷ ŪɃɆ ȺɆɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	3 D
	ůxx (kPa)	ůyy (kPa)
1	0	22
2	7	27.5
3	21	33
4	42	22
5	56	11
6	70	11
7	56	11
8	35	22
9	21	33
10	7	27.5

Aɟ. Ƭɧɛɓɞg ɟ ´ɧ Ǔɟ ɘůǛǕǰ Ұ´ ɟɞɠ ǛŬǔǓɘɘҰ	ɗɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	3.5 D
	ůxx (kPa)	ůyy (kPa)
1	13	36
2	26	36
3	52	24
4	71.5	18
5	78	12
6	65	18
7	52	24
8	26	36
9	13	36
10	6.5	30

Aɟ. Ƭɧɛɓɞg ɟ ´ɧ Ǔɟ ɘůǛǕǰ Ұ´ ɟɞɠ ǛŬǔǓɘɘҰ	ɗɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4 D
	ůxx (kPa)	ůyy (kPa)
1	0	33
2	14	44
3	35	38.5
4	63	33
5	77	11
6	105	16.5
7	84	21
8	56	33
9	35	38.5
10	14	44

Aɟ. Ƭɧɛɓɞg ɟ ´ɧ Ǔɟ ɘůǛǕǰ Ұ´ ɟɞɠ ǛŬǔǓɘɘҰ	ɗɟ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	4.5 D
	ůxx (kPa)	ůyy (kPa)
1	14	38.5
2	21	44
3	42	49.5
4	63	38.5
5	91.5	22
6	98	22
7	91.5	27.5
8	56	38.5
9	42	55
10	21	44

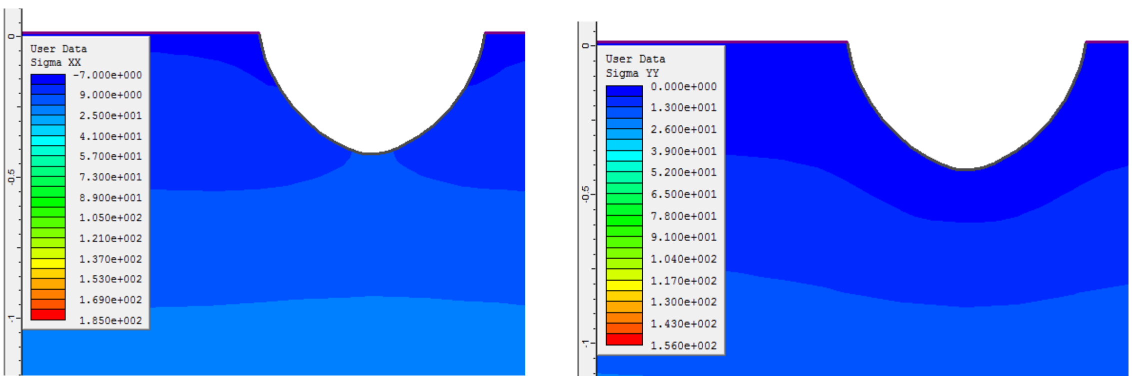
Aɟ. Ƭɧɛɓɵɡ ȷ ˊɧ Ŭɟ ɘůŰǰ Ÿ ˊ ɟɵɠŰŬŭŬɜɘŸ	ȡȷ ŪɃɆ ȺɆɟ ɋ Ʌ¢ Ɇ¢ Ɇ	5 D
	ůxx (kPa)	ůyy (kPa)
1	14	44
2	35	49.5
3	56	49.5
4	77	38.5
5	105	33
6	112	27.5
7	105	33
8	77	44
9	56	49.5
10	28	49.5

ȷ .3. ũ Λ ȷ ū ¢ ɀ ȷ ȼ ȷ Ⱦ ȷ ȼ ȷ Ɂ Ƀ ɀ ¢ Ɇ ȼ ɋ Ɂ ȼ ȷ Ɇ Ⱥ ɋ Ɂ ɄɃ Ɉ
Ʉ ȷ Λ¢ ɉ Ū¢ Ɇ ȷ Ɂ ȷ ɄɃ ȼ Ƀ ȿ Ƀ ũ Ⱡ ɀ ȾɃ PHASE 2

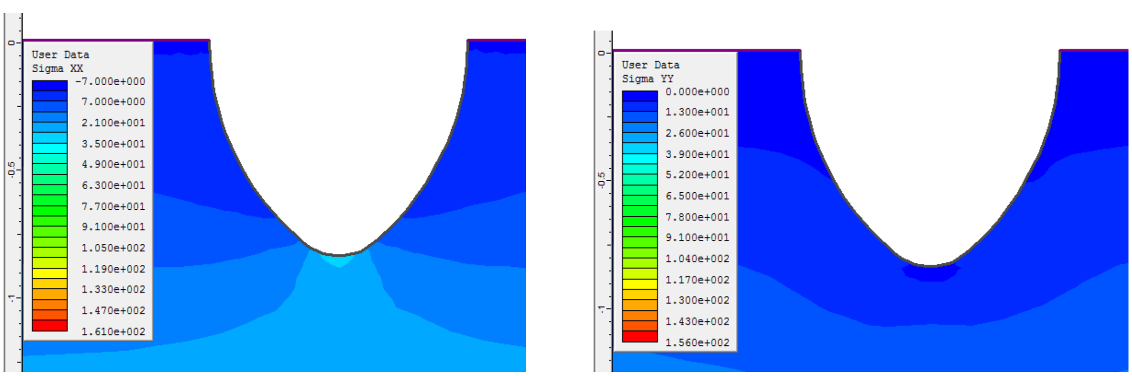
ȼ Ŭ Ŭɘɧɚɕgɗ Ŭ ɔɉ Ŭ ɪɐ ɛ Ŭ Ű Ŭ ɜŬ ɪŬ ɜ ɕɪ ɞ ɡ ɜ ɚ gɉ ɑ ɠ Ű ɗ ɜ Ŭ ɪɜ ɗ ů ɗ Ű ɗ ɠ Ŭɜ Ű Ŭ ɐ ɠ ɚ Ŭ Ű Ɏ ů Ű ɗ ɠ Ű g ´ gɗɛ ɏ ɜ Ŭ ɛ Ů Ű ɓ Ɏ ɗ ɠ Ŭ ů ɚ Ŭ ɪɐ ɠ ɚ Ŭ ´ Ɏ ɜ Ű ů Ů Ŭ ɜ Ŭ ɪ ɉ Ɏ ɛ Ů Ű ɗ ůɪ ů Ű ɗ Ű g gɚɘ ɪ ´ gɗɛ ɏ ɜ Ŭ ɚ Ŭ Ű ɗ ɔ Ů ɛ Ű ɉ ɗ Ŭ Ű ɗ ɠ Ů Ŭ ɪɐ ɠ Ŭ ɤ ɔ ɪ - ´ gɗɛ ɏ ɜ Ŭ, ŭ ɗ ɚ Ŭ ɪɐ Ű ɗ ɔ Ů ɛ Ű ɉ ɗ Ŭ Ű ɗ ɠ Ŭ ů ɚ Ŭ ɪɐ ɠ Ű ɗ ɠ Ű Ɏ ɪ ɉ g. ũ ɚ Ŭ ɚ Ɏ ɗ Ů ´ Ű ɑ Ű ů ɗ ´ Ŭ ɉ gů ɚ Ɏ ɜ Ű ɚ ɚ Ű ɛ ɏ ɠ Ű ɜ Ű Ɏ ů Ŭ ɜ ůxx ɚ Ŭ ůyy ɛ ɧ ɜ ɔ ɚ Ŭ Ɏ ɗ Ŭ ů ɚ Ŭ ɪɐ ɠ D, 2D, 3D, 4D, ɚ Ŭ Ű Ɏ Ŭ ɪ ɜ gů Ŭ ů Ŭ ɉ Ɏ, ɔ ɚ Ŭ ɚ ɧ ɔ g ɠ ɔ Ŭ ɜ ɐ Ŭ gů ɗ ɠ.

A.3.1. ȷ Λũ Ɫ ȿ Ƀ -Ɫ ȿ Ɉ ɋ ɸ Ⱥ Ɇ Ɉ ȿ ȾɃ ɄɈ Ū ɀ Ⱥ Ɂ ȷ , ɀ Ⱥ Ⱥ Ʉ ȷ ū ¢
Ɇ ɉ ¢ ɀ ȷ ȼ Ƀ Ɇ ȼ Ƀ ʔ Ƀ Ɉ ɀ ¢ Ⱦ Ƀ Ɉ Ɇ 1/3 D.

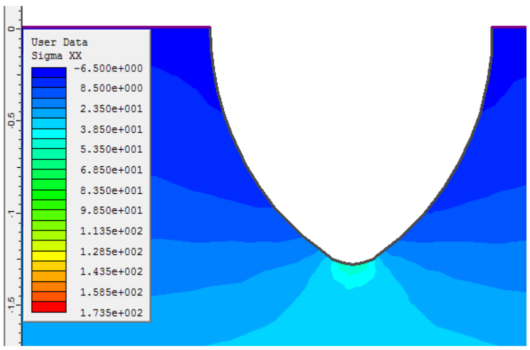
- D

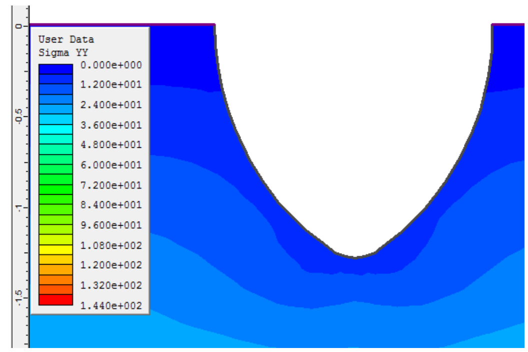


- 2D

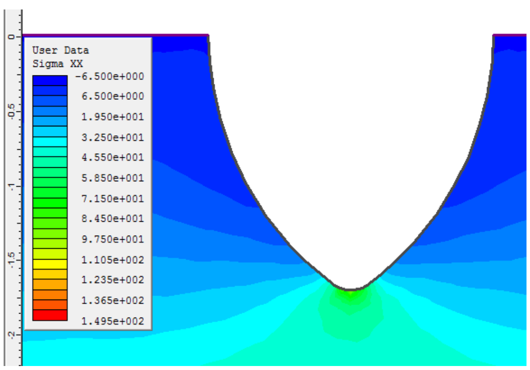


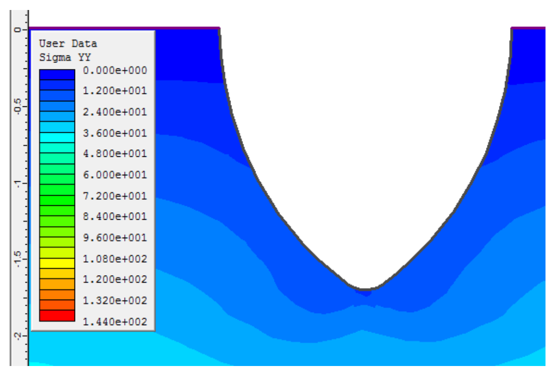
- 3D





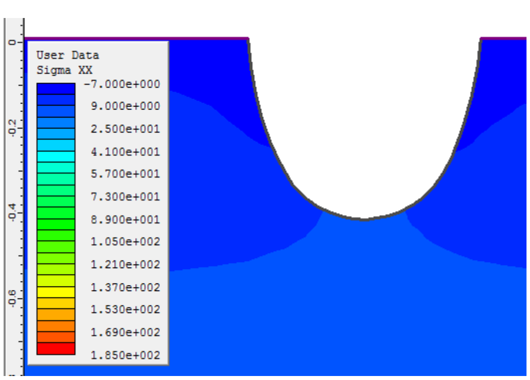
- 4D

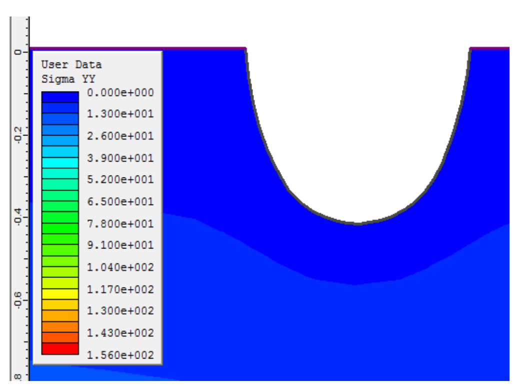




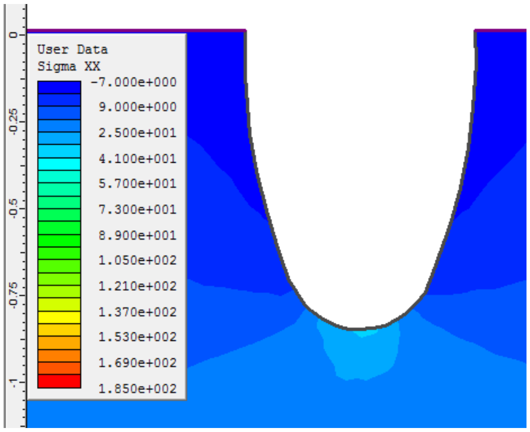
A.3.2. ȷ Λũ Ⱡş Ƀ-Ⱡş Ɉ ɋ ȹȺɆ Ɉ ş ȾȾɃ ɄɈ Ūʐ ȺȜ ȷ , ʐ Ⱥ ȺɄȷ ū ¢ Ɇȷ ¢ ʐ ȷ ȼ ɃɆ ȼ Ƀʔ ɃɈ ʐ ¢ ȾɃɈ Ɇ 2/3 D.

- D





- 2D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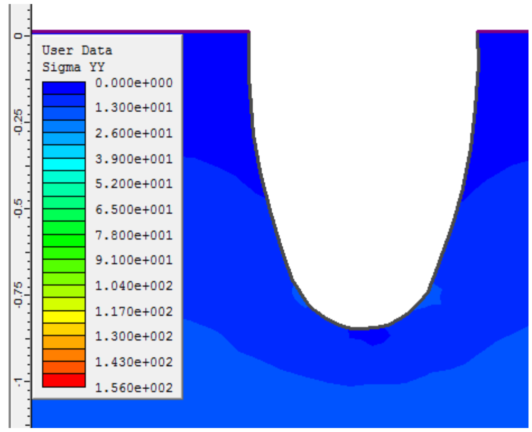
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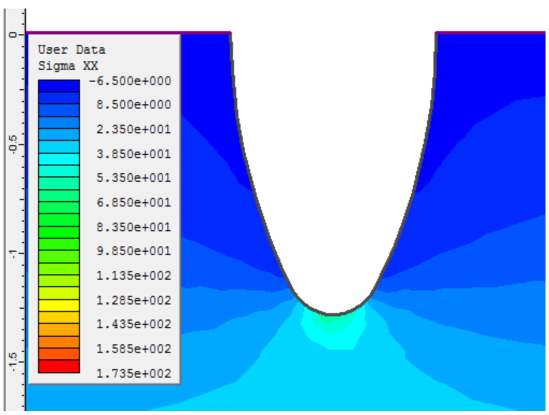
- 3D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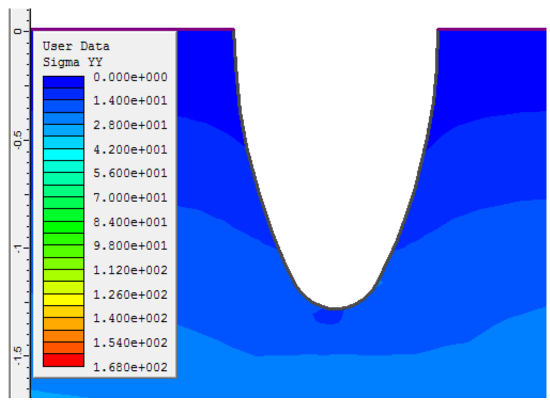
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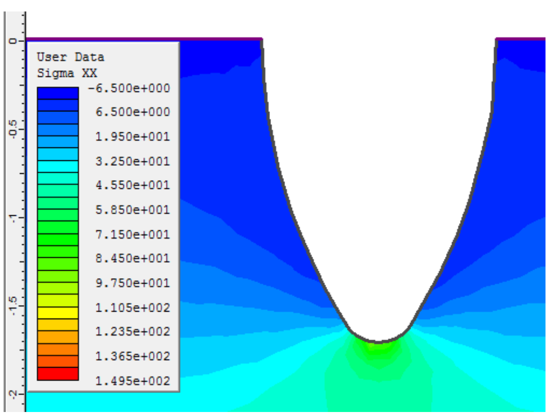
- 4D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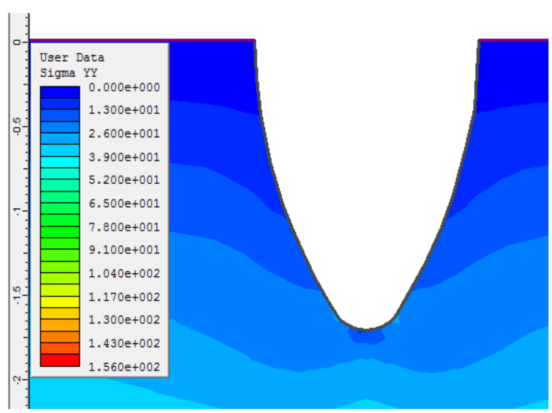
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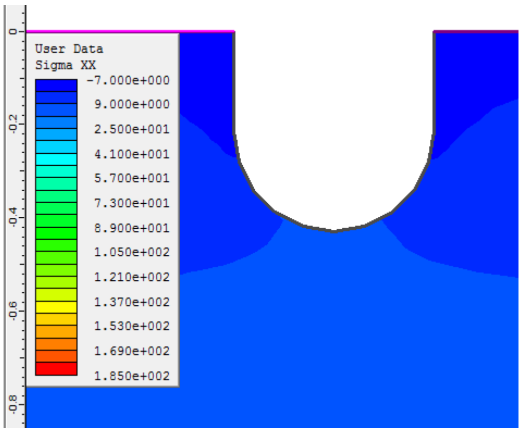
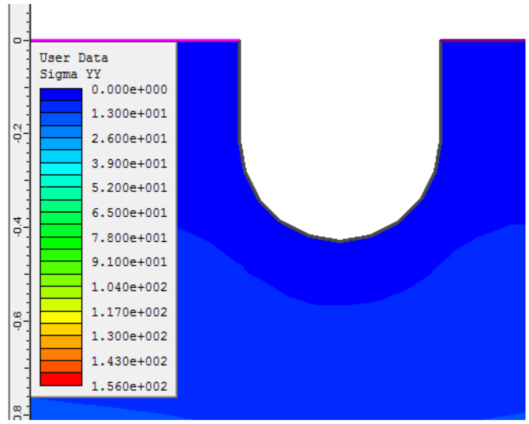
7.800e+001
9.100e+001
1.040e+002
1.170e+002
1.300e+002
1.430e+002
1.560e+002

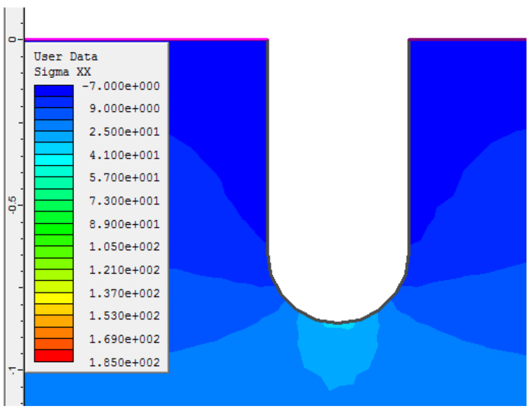
A.3.3. ȷ Λũ Ŀş Ƀ-Ŀş Ɉ ɋ ȹȺɆ Ɉ ş ĦƮ Ƀ ɄɈ Ūɀ ȺɁ ȷ , ɀ Ⱥ ȺɄȷ ū ¢
Ɇǰ ¢ ɀ ȷ ȼɃɆ ¢ ɀ ĦƮ Ɉ Ʈ ş ĦɃ Ɉ ɀ ¢ ƮɃ Ɉ Ɇ D.

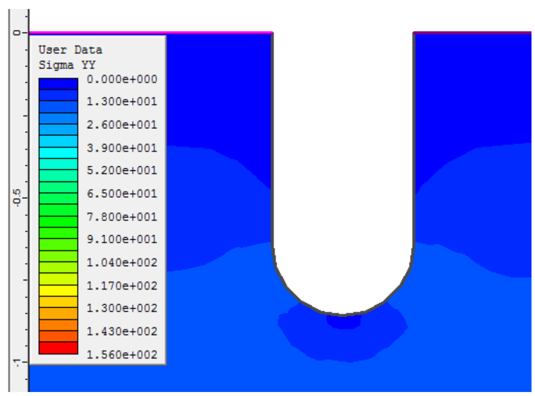
- D



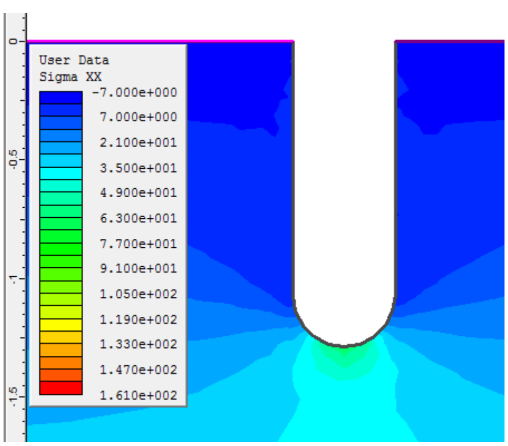


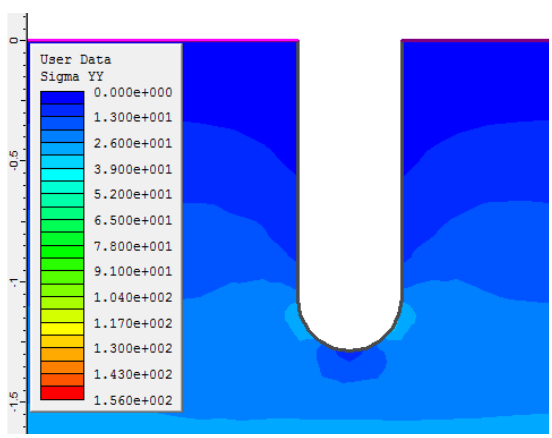
- 2D



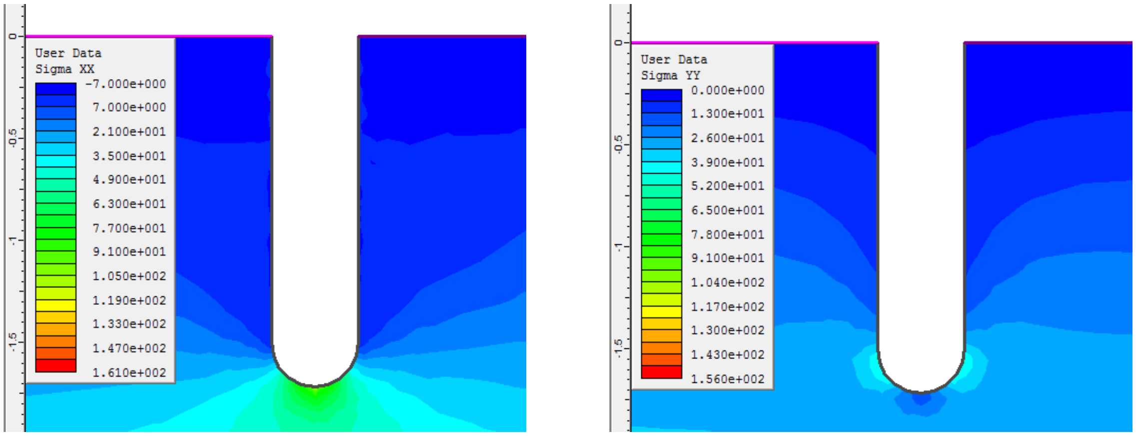


- 3D



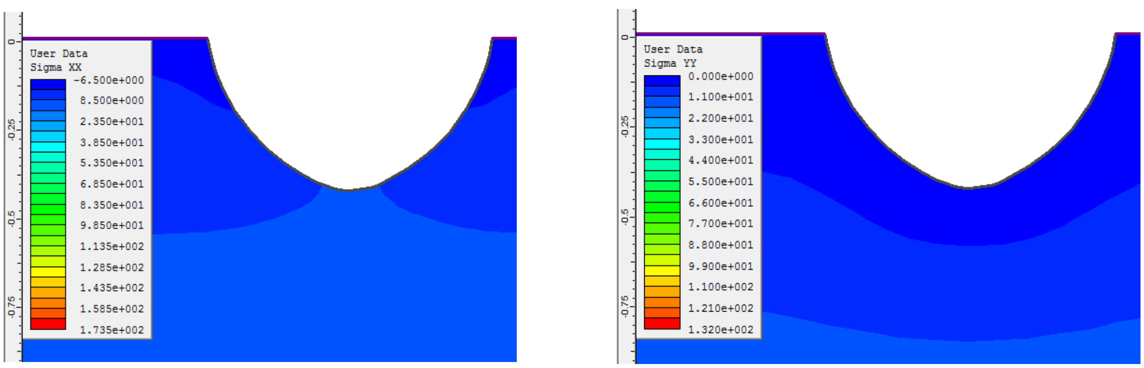


- 4D



A.3.4. ȷ ʐ ʐ Ƀ-ȷ Λũƚʂ ɋ ȹȺɆ Ɉ ʂ ȾȽɃ ɄɈ Ūʐ Ⱥʔȷ , ʐ Ⱥ ȺɄȷ ū ¢
Ɇʝ ¢ ʐ ȷ ȼɃɆ ȼɃʔɃɈ ʐ ¢ ȽɃɈ Ɇ 1/3 D.

- D



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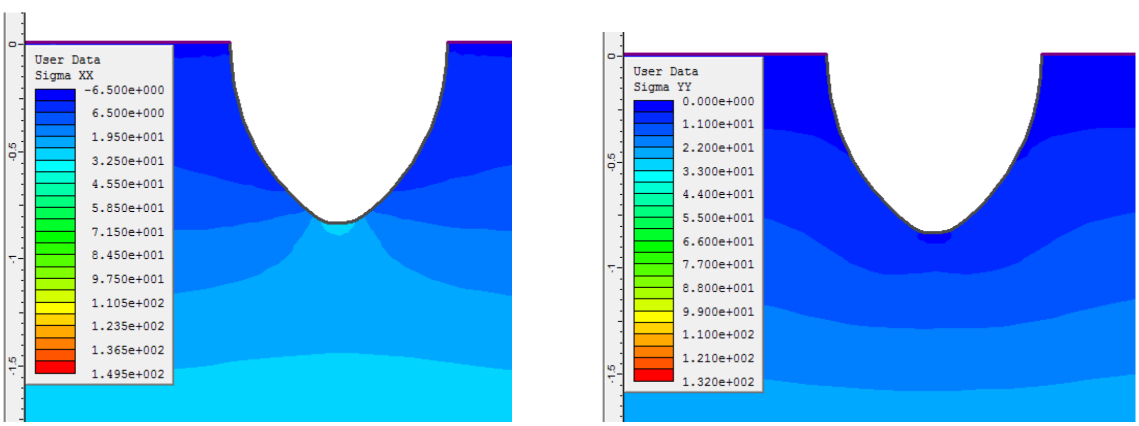
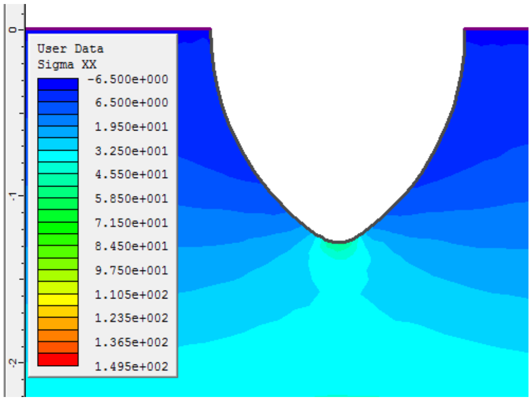
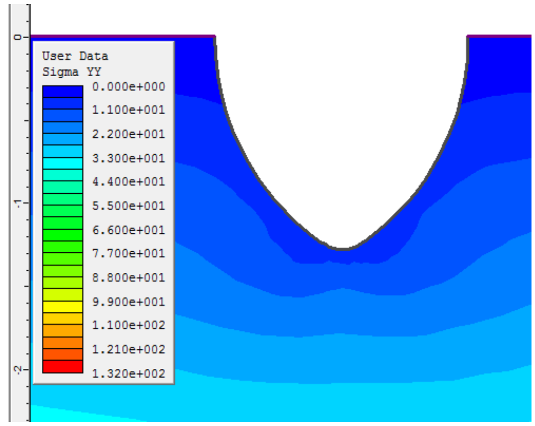
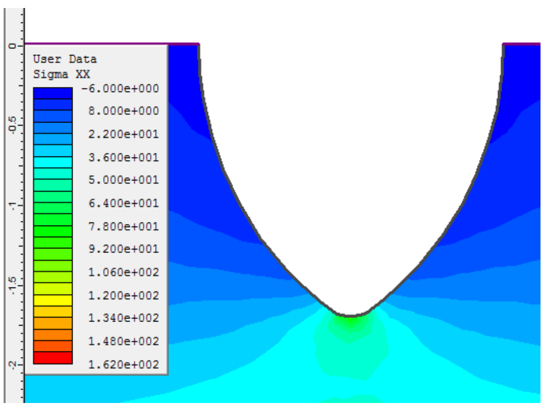


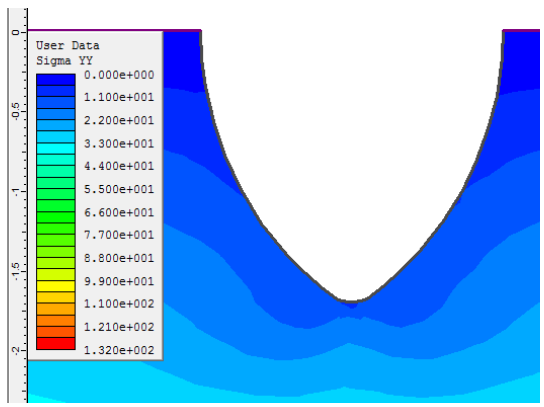
- 3D





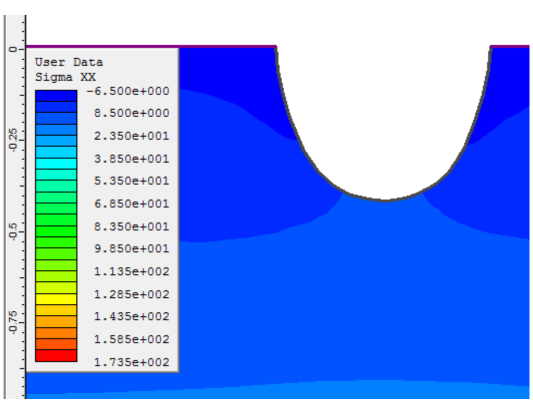
- 4D

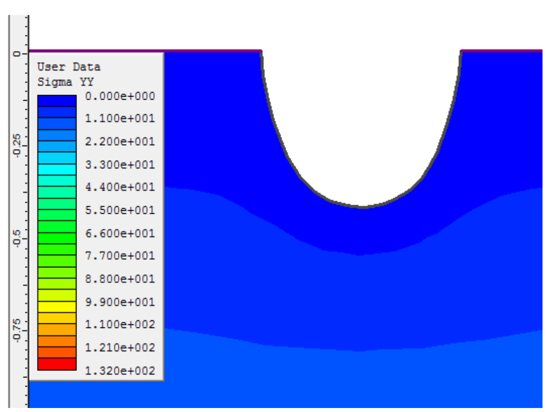




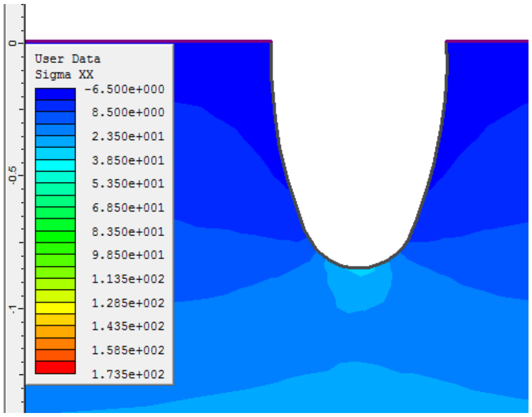
A.3.5. ј ʐ ʐ Ƀ-ј Λũƚʂ զ փȺɆ Ɉ ʂ ɆƮȻ ɄɈ Ūʐ Ⱥʔ ј , ʐ Ⱥ ȺɄј ū ¢ Ɇj ¢ ʐ ј ȼɃɆ ȼɃʔ ɃɈ ʐ ¢ ȾɃɈ Ɇ 2/3 D.

- D





- 2D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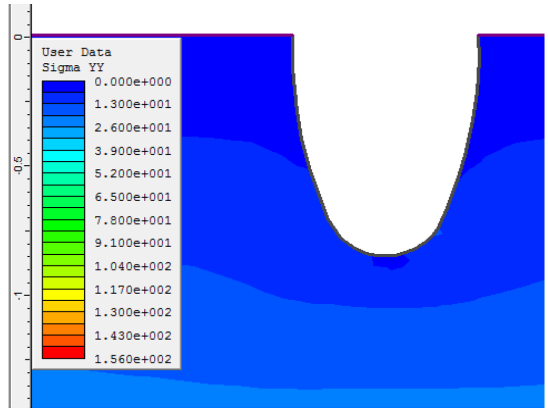
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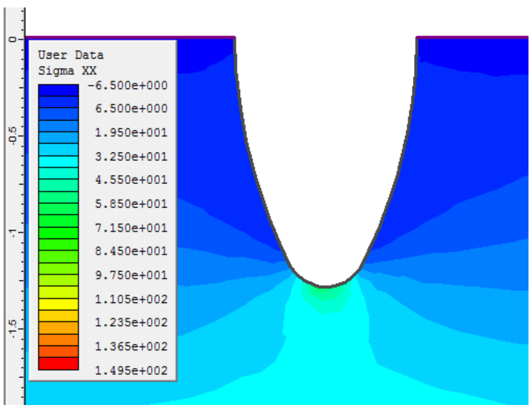
- 3D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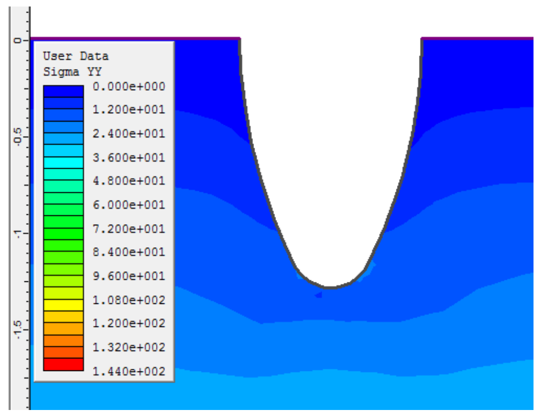
1.495e+002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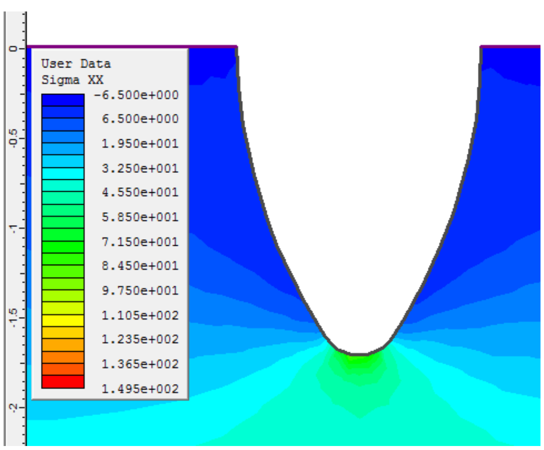
- 4D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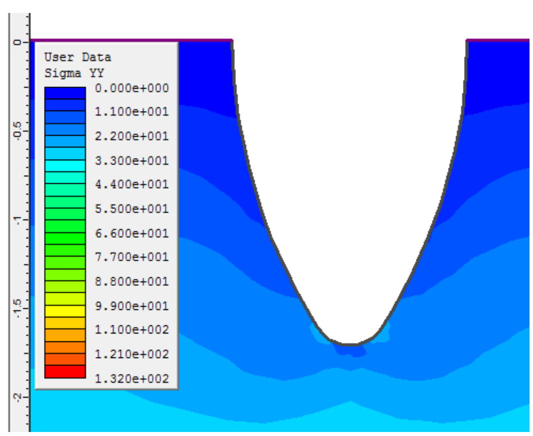
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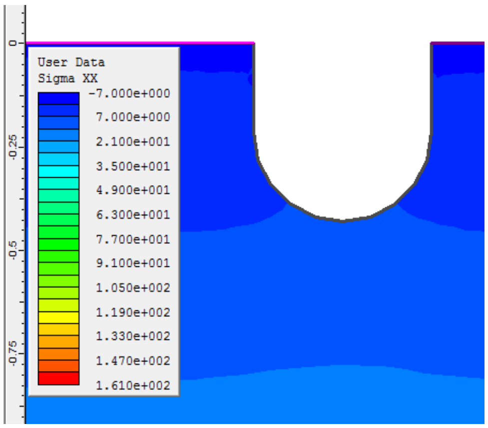
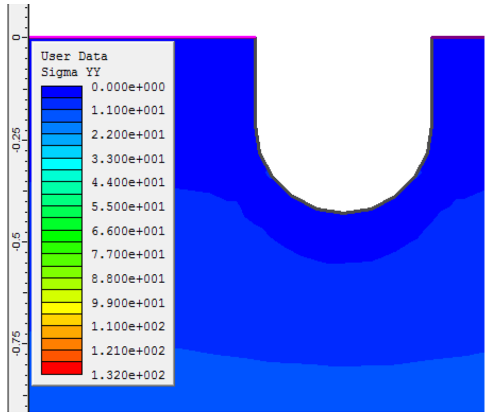
9.900e+001
1.100e+002
1.210e+002
1.320e+002

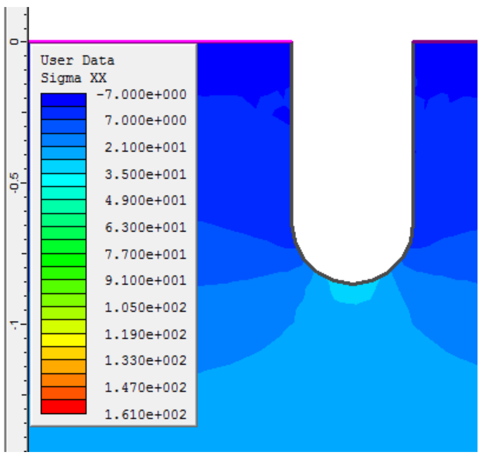
A.3.6. ȷ ɀ ɀ Ƀ-ȷ Ʌũƚ ɋ ȹȺɆ Ɉ ȿ ȾȺ ɄɈ Ūɀ ȺɁ ȷ , ɀ Ⱥ ȺɄȷ ū ¢
Ɇȷ ¢ɀ ȷ ȼɃɆ ¢ɀ ȾȺɈ Ⱥȿ ɃɈ ɀ ¢ȺɃɈ Ɇ D.

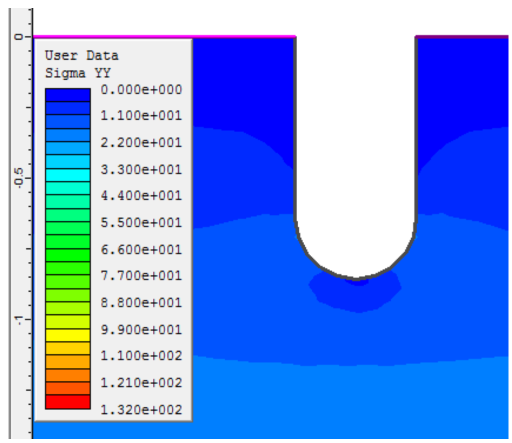
- D



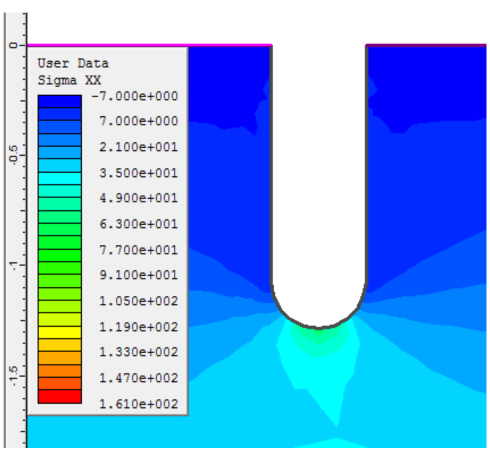


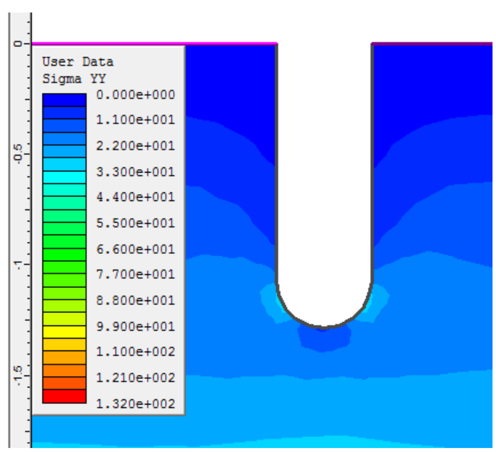
- 2D



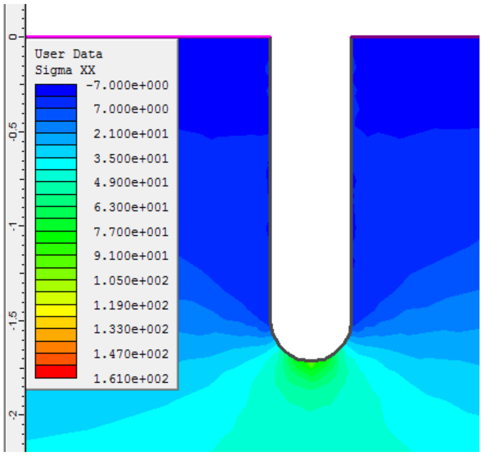


- 3D





- 4D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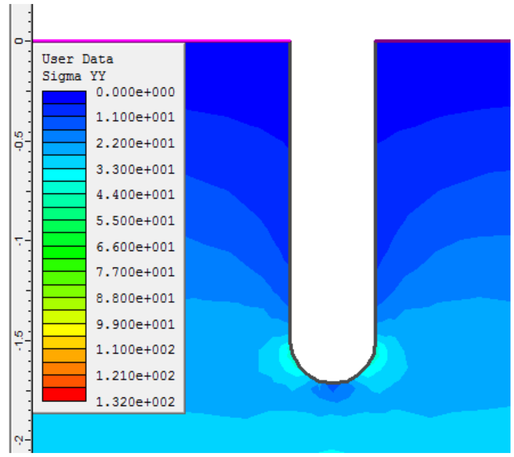
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7.700e+001
8.800e+001
9.900e+001
1.100e+002
1.210e+002
1.320e+002

Ј.4. Ɉ ՍɃȿ ɃũɆȥ ȺȢ ȺɆ ȾЈ ȼЈ ȾɃɅɈ ũ ȺɆ Ј Ȣȼ ȽȹɅЈ ɆȺɆ Ⱥȹ ũ ɃɈ Ɇ Ɇȼ ȻɆ ȹȽȺɪɆȹɈ Ɇȼ ȼɃɈ Ј ũɋ ũɃɈ

ƃѮďɞɠ Ůǁ Ȥ ɖůɖɠ		Ј ɜӰűȤ Ŭůɖ P (kN/m)		
y/D	y (m)	Ј ȥ ȥ Ƀ-Ј ɅũȽȿ ɋ ȹȺɆ, 1/3 D	Ј ȥ ȥ Ƀ-Ј ɅũȽȿ ɋ ȹȺɆ, 2/3 D	Ј ȥ ȥ Ƀ-Ј ɅũȽȿ ɋ ȹȺɆ, D
0,1	0,0429	0,000	0,000	0,000
0,5	0,2145	0,000	0,001	0,000
1	0,429	0,000	0,463	0,588
1,5	0,6435	0,641	1,145	2,423
2	0,858	1,095	2,515	2,992
2,5	1,0725	1,288	3,575	3,899
3	1,287	1,797	4,340	6,138
3,5	1,5015	2,437	3,930	7,388
4	1,716	2,592	5,268	9,150
4,5	1,9305	2,830	7,359	11,130
5	2,145	3,252	8,396	12,590

ƃѮďɞɠ Ůǁ Ȥ ɖůɖɠ		Ј ɜӰűȤ Ŭůɖ P (kN/m)		
y/D	y (m)	Ј ɅũȽȿ Ƀ-Ƚȿ Ɉɋ ȹȺɆ, 1/3 D	Ј ɅũȽȿ Ƀ-Ƚȿ Ɉɋ ȹȺɆ, 2/3 D	Ј ɅũȽȿ Ƀ-Ƚȿ Ɉɋ ȹȺɆ, D
0,1	0,0429	0,000	0,000	0,000
0,5	0,2145	0,000	0,000	0,000
1	0,429	0,000	0,994	0,960
1,5	0,6435	0,733	1,544	2,576
2	0,858	1,332	2,697	3,882
2,5	1,0725	1,500	4,226	4,134
3	1,287	1,800	5,312	6,304
3,5	1,5015	2,200	5,879	7,294
4	1,716	2,503	6,300	9,466
4,5	1,9305	3,445	7,170	11,517
5	2,145	3,821	9,041	13,649

Ʉȷ Ʌȷ Ʌɇ ₵ ʐ ȷ ȡ

ũɅȷ ū ₵ ʐ ȷ ɇ ȷ ȹɈ ʔ ȷ ʐ ȾƮ ɋ ʔ Ⱥʔ ɇ ȷ ɇ ȾƮ ɋ ʔ ʐ ȺũȺŪ ɋ ʔ ɇ ɃɈ ȷ ũ ɋ ũ ɃɈ ɃɄ ɋ Ɇ Ɉ ɄɃȿ Ƀũ ȾɆ ɇ ₵ Ƭ ȷ ʔ ȷ ɄɃ ɇ Ƀ ʔ Ƭ ɋ ȹȾƮ ȷ CON3DF ʐ Ⱥ ȺȾɆ ȷ ũ ɋ ũ ₵ ɇ ₵ Ɇ ȷ ʔ ɇ Ƚȹ Ʌȷ Ɇ₵ Ɇ ɇ ɃɈ Ⱥȹȷ ū ɃɈ Ɇ

ɄǓɈ ɞɡůɘƳɛɜɜȝ ɔɘǓ ɚɧɔɞɡʃ ɔǓɞ Ǘɡůɖʃ, ǕǕ ɔɈ Ǔɩɐɛ ǓǕ ɛɧɜɞ ɔɘǓ Ƴɚɞɡʃ 4 Ǘɨ ´ɞɡʃ ŭɘǓɏɈ ůǓɤ ɜ Ǔ ɧ Ǘɡʃ 10 ɡ ´ɞɚɞɔɘůɖɏɜǗʃ, ŭɖɚ.:

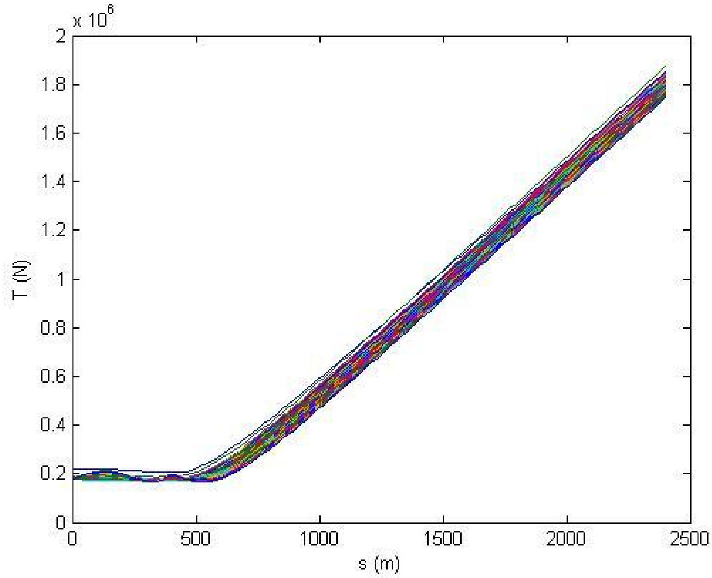
- x = 1 m, z = 0 m, ɤ = 0.2 rad/sec
- x = 0 m, z = 1 m, ɤ = 0.2 rad/sec
- x = 1 m, z = 0 m, ɤ = 0.6 rad/sec
- x = 0 m, z = 1 m, ɤ = 0.6 rad/sec

ɘǓɘɔɘǓ ɓƳɖɖ Ǔůɩɿ ɟɖůɖʃ ůǓɚɡɞ-ǓɈ ɔɚɩ ŭɖ ´ɡɖɛɏɜǓ, 2D, 2.5D, 4D.
Ɉ ´ Ǔɖɡɛ ɶǓǕǕ ɧǗ 2 ɓǓůɚɞɑǗ ´ɞɘ ŭɘǓɏɈ ůǓɤ ɜ (x = 1, ɤ = 1 rad/sec ɘǓ z = 1, ɤ = 1 rad/sec) ɏɞɞɡɜ ǓǕǕůɖǓ ǓǓɚɡǗƳ ůǗ ɘǓɩƳɚǓ 5 Ǘɖʃ ´ Ǔɞɨ ůɖʃ ǓɔǓůɖǓʃ ɘǓ ɛ ´ɞɈɞɨ ɜ ǓɞɈ ɖůɶɞ ´ɞɖɖɞɨ ɜ ɔɘǓ ůɨ ɔɚɈ ɘůɖ ɛ ǓǕǕ ŭɘǓɈ Ƴɛ ɛ ǓǕ ´ɞɡ Ǔɞɚɞɡɖɞɨ ɜ.
₵ Ǔ ɘǗƳɜǓǓ Ǔ Ǔɩɐ ʃ ǓɩƳɩɞɡʃ-Ǔɤɔɞɨ ´ɞɡ ǓǕǕƳɛǓǕǕ ǓɞǓ ůɞɐ ɛǓǗʃ Ǘɧɜɞɡ ɛɐɘɞɡʃ (2/3)D, ɤ ʃ ɖ ɛɏůɖ ´ Ǔ ɑ Ǘɤ ůɖ Ǔ ɧ ɧɚǓʃ Ǘʃ ɡ ´ɞɚɞɔɘůɖǓůǓʃ.
₵ ´ Ǔ ɑ Ǘɤ ůɖ Ǔɛ ɛ ɞ-ǓɈ ɔɚɩ ŭɞɡʃ ´ɡɖɛɏɜǓ ŭǓ ´ Ǔɞɡůɘ ƳǓǓǕǕ ɘǓɑ ʃ ɡ ´ Ƴɞ ǓǓ Ǔɘɐʃ ǓǓɩɞɈƳ ůǗ ůɨ ɔɚɈ ɘůɖ Ǘɖʃ Ǔ ɑɈ Ǔůɖʃ ´ɞɡ ´ Ǔɞɡůɘ ƳǓ Ǘ ɘƳɖǓɡɚɩ ɧ ůǗ ɘǓɩƳɚǓ 5.

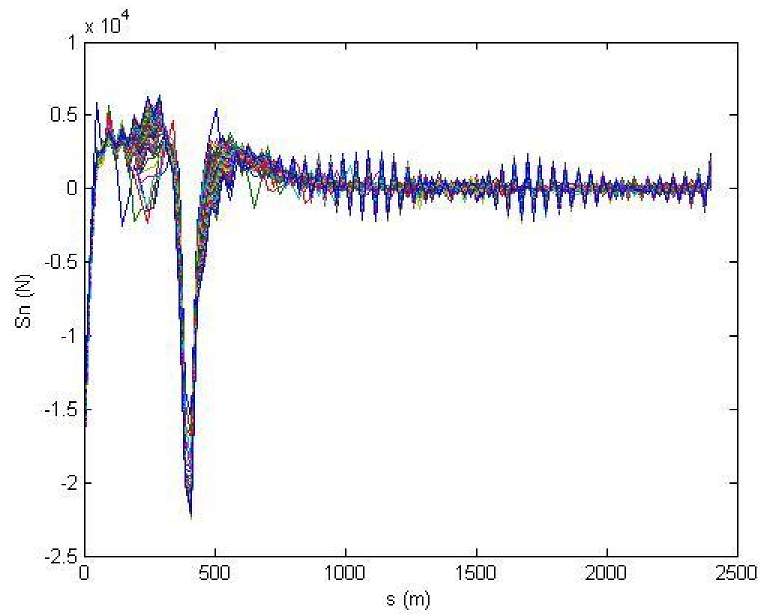
ɇ ɞ ´ Ǔ ɧɜ ´ Ǔ ƳǗɖɛ Ǔ Ǔ ɚǓǗɩ ɜǓǕǕ ůǗɜ ǓɏɘɚɜɖǗɤ ɜ ŭɡɜǓɛɚɩ ɜ ǓǕǕǗɚɩ ɜ ɛǓǓɑ ɜ ůǗ ´ Ǔɩɶ Ǘɡ ɞɈɧɜɞɡ ɛ Ǔ ɓƳůɖ Ǘɡʃ ´ Ǔ Ǔ Ƴɜɤ Ǘɨ ´ɞɡʃ ŭɚɔǓůɖʃ ɘǓ ɛ Ǔ ůɞǕǗɚɐ ǓǓɩɞɈƳ ůǗɜ Ǔ ɑɈ Ǔůɖ Ǘɡ ɓƳɖɞɡʃ Ǔůɩɿ ɟɖůɖʃ ´ɞɡ ǓɛǓɞ ɘɡɈɚ ǕǓɞʃ ´ ǓƳɔɞɜǕǓʃ ɛ ǕǕǓɞɚɐ ʃ Ǘɖʃ ǓǕɑɈ Ǔůɖʃ Ǘɡ ǓɩƳɩɞɡʃ.

ф.1 Ѧɂ Ѧʂ Ƚɂ ¢ ɇ ɋ ʔ ɸɟ ʔ ȷ ɀ ȽƮ ɋ ʔ Ѧʔ ɇ ȷ ɇ ȽƮ ɋ ʔ ɀ Ѧũ ѦŪ ɋ ʔ Ɇɇ Ƀ ɄѦɸȾɃ ɇ Ƀɟ
ɉ ɅɃ ʔ Ƀɟ

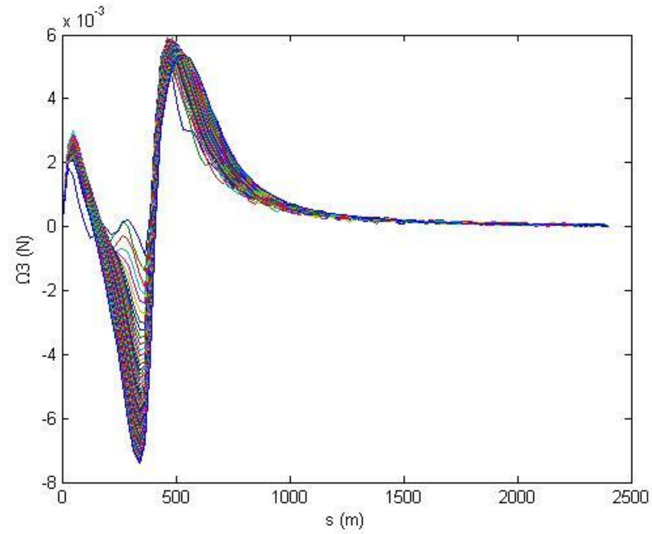
ɸȽѦũ ѦɅɆ¢ : x = 1 m, z = 0 m, ɤ = 0.2 rad/sec



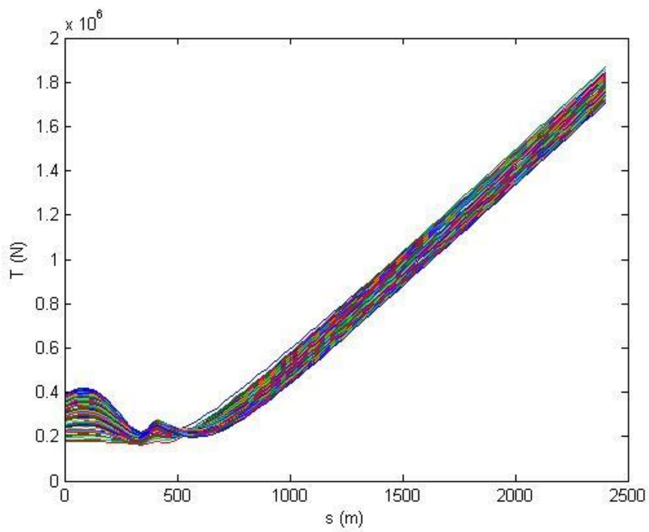
ɸɘŸɔɟ Ŭɛ ɛ Ŭф.1.1 ¢ ůɡɜɞɘɐ ɏɜŰŰůɋ T ɘŬŰŸ ɛ ɐɘɞɠŰɋɠ ɘŬŰŰůɘŮɡɐɠ
ɔɘŬ ɓŸɗɞɠ Ůůɢ ɟ ɋůɋɠ 2D ůŰɛɜ ˊ ɡɗɛ ɏɜŬ



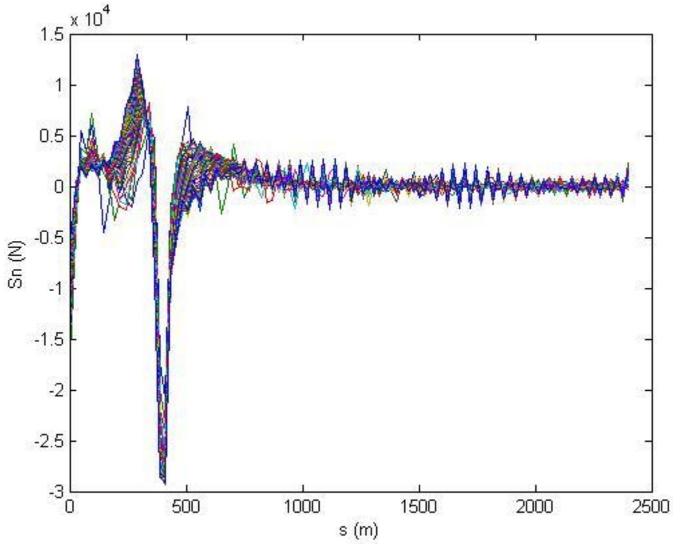
ɸɘŸɔɟ Ŭɛ ɛ Ŭф.1.2 ¢ ŭɘŬŰɛ ɋŰɘɐ ŭɨ ɜ Ŭɛ ɋ Sn ɘŬŰŸ ɛ ɐɘɞɠŰɋɠ ɘŬŰŰůɘŮɡɐɠ
ɔɘŬ ɓŸɗɞɠ Ůůɢ ɟ ɋůɋɠ 2D ůŰɛɜ ˊ ɡɗɛ ɏɜŬ



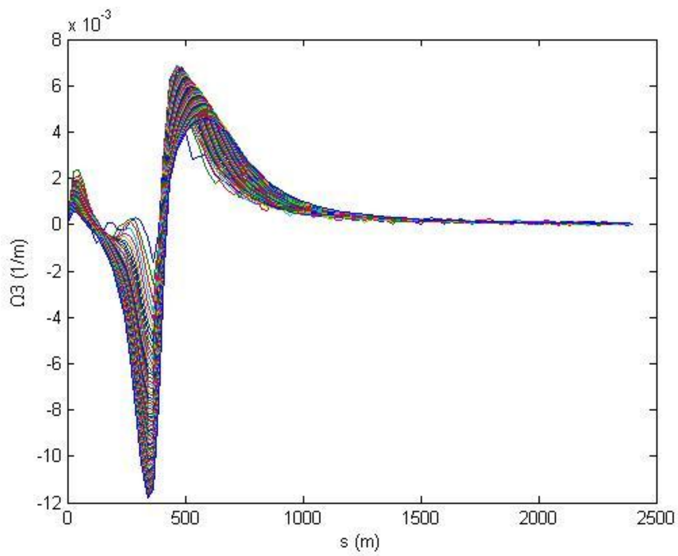
ɸǝŸɔɟ Ŭɛ ɛ Ŭ ȸ.1.3 ¢ ǝŬɛ ´ gǝɧŰɖŰŬ ɋ 3 ǝŬŰŸ ɛ ɐǝɞɠ Űɖɠ ǝŬŰŬůǝŮgɐɠ
ɔɘŬ ɓŸɖɞɠ Ůǝůɢɩ ɟ ɖůɖɠ 2D ůŰɛɜ ´ gɖɛ ɏɜŬ



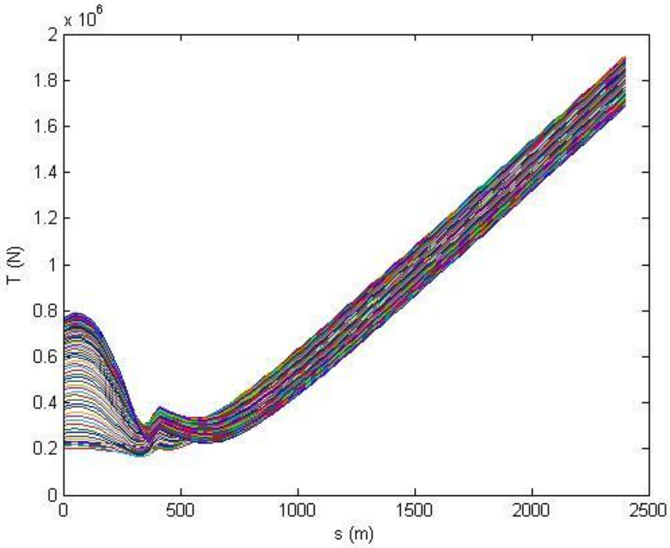
ɸǝŸɔɟ Ŭɛ ɛ Ŭ ȸ.1.4 ¢ ůgɜɞǝɘɐ ɏɜŰŬůɖ T ǝŬŰŸ ɛ ɐǝɞɠ Űɖɠ ǝŬŰŬůǝŮgɐɠ
ɔɘŬ ɓŸɖɞɠ Ůǝůɢɩ ɟ ɖůɖɠ 2.5D ůŰɛɜ ´ gɖɛ ɏɜŬ



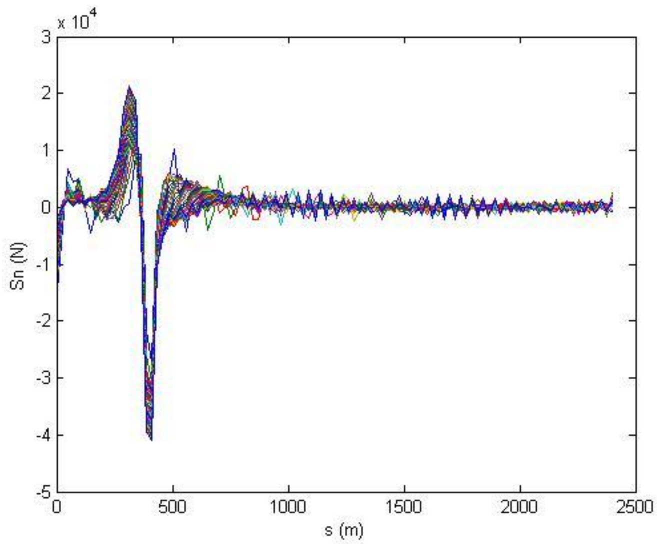
φəŸɔɟ Ŭɛ ɛ Ŭȡ.1.5 ¢ ŭэŬŰɛɖŰəɐ ŭɨ зŬɛɖ Sn əŬŰŸ ɛɐəɞɠŰɖɠəŬŰŬůəŮɡɐɠ
ɔəŬɓŸɗɞɠŮəůɢı ɟɖůɖɠ 2.5D ůŰɛз ´ ɡɗɛɏзŬ



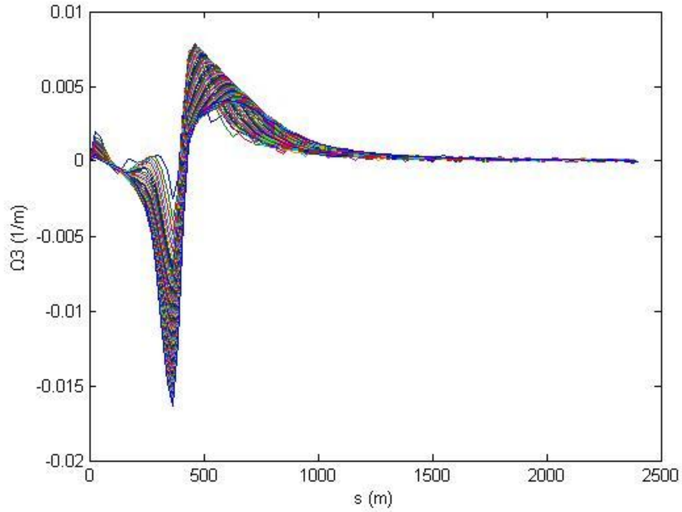
φəŸɔɟ Ŭɛ ɛ Ŭȡ.1.6 ¢ əŬɛ ´ ɡəɧŰɖŰŬɋ 3 əŬŰŸ ɛɐəɞɠŰɖɠəŬŰŬůəŮɡɐɠ
ɔəŬɓŸɗɞɠŮəůɢı ɟɖůɖɠ 2.5D ůŰɛз ´ ɡɗɛɏзŬ



ɸɘƳɔɟ Ŭɛ ɛ Ŭȸ.1.7 ¢ ůgɜɞɚɘɐ ɏɜŰŬůɖ T ɘŬŰƳ ɛ ɐɘɞɠ Űɖɠ ɘŬŰŬůɘŮgɐɠ
ɔɘŬ ɓƳɗɞɠ Ůɚůɢ ɟ ɖůɖɠ 4D ůŰɞɜ ´ gɗɛ ɏɜŬ

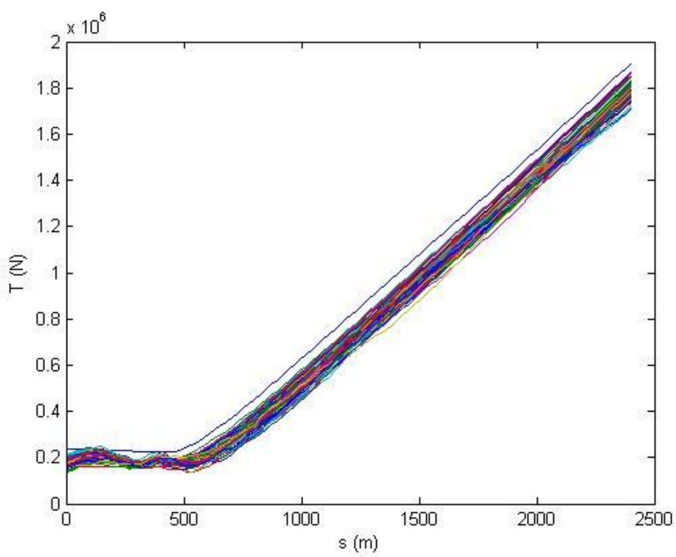


ɸɘƳɔɟ Ŭɛ ɛ Ŭȸ.1.8 ¢ ŭɘŬŰɛ ɖŰɚɐ ŭɨ ɜ Ŭɛ ɖ Sn ɘŬŰƳ ɛ ɐɘɞɠ Űɖɠ ɘŬŰŬůɘŮgɐɠ
ɔɘŬ ɓƳɗɞɠ Ůɚůɢ ɟ ɖůɖɠ 4D ůŰɞɜ ´ gɗɛ ɏɜŬ

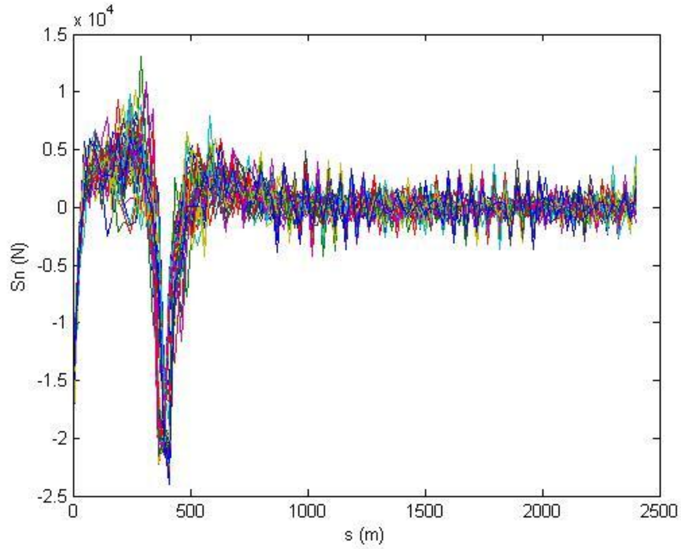


ꝕəŸɔɟ Ŭɛɛ Ŭȸ.1.9 ¢ əŬɛ´ ɡəɦŰɖŰŬq 3 əŬŰŸɛɐəɞɠŰɖɠəŬŰŬůəŮɡɐɠ
ɔəŬɓŸɗɞɠŮɜůɞ ɟɖůɖɠ4D ůŰƈɜ ´ ɡɗɛɏɜŬ

- ꝕɫȺũȺɅƗ¢ : x = 0 m, z = 1 m, ɤ = 0.2 rad/sec

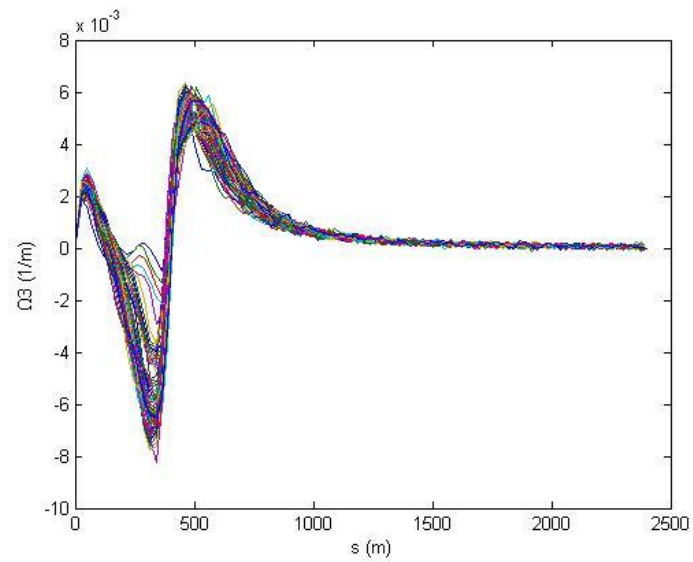


ꝕəŸɔɟ Ŭɛɛ Ŭȸ.1.10 ¢ ůɡɜɞəəɐ ɏɜŰŬůɖ T əŬŰŸɛɐəɞɠŰɖɠəŬŰŬůəŮɡɐɠ
ɔəŬɓŸɗɞɠŮɜůɞ ɟɖůɖɠ2D ůŰƈɜ ´ ɡɗɛɏɜŬ



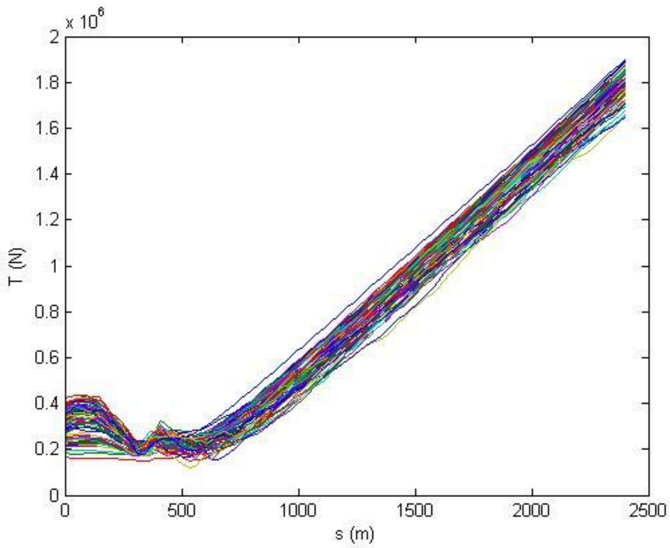
ϕэΎϿɟ Ŭ̀ɛ ɛ Ŭȸ.1.11 ¢ ŭэŬ̋ɛ̋ɖ̋Ǘɘɐ ŭɨɜŬɛɖ Sn эŬ̋Ύ ɛɐэɞɠ̋Ű̋ɖɠ эŬ̋Ŭ̋ůэŮɡɐɠ

ɔэŬƃΎɗɞɠŮ̊ůɢɩ ɟɖůɖɠ 2D ůŰ̋ɛɜ ´ ɡɗɛɏɜŬ

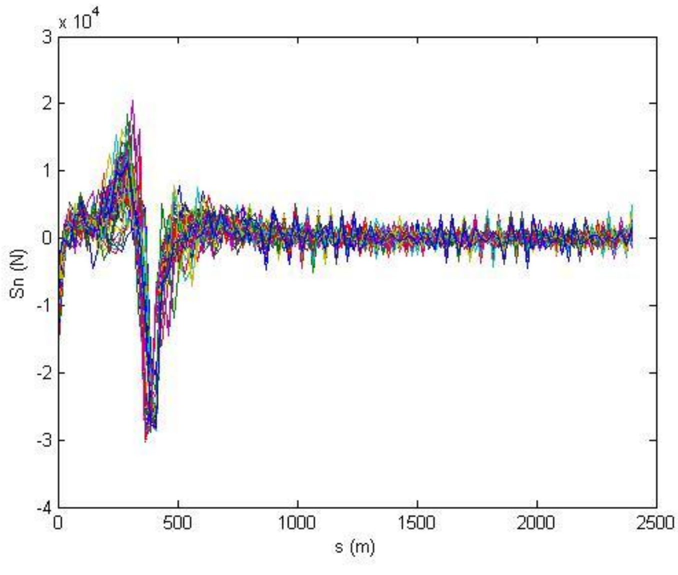


ϕэΎϿɟ Ŭ̀ɛ ɛ Ŭȸ.1.12 ¢ эŬ̀ɛ ´ ɡɚɦŰ̋ɖŬ̋ɋ 3 эŬ̋Ύ ɛɐэɞɠ̋Ű̋ɖɠ эŬ̋Ŭ̋ůэŮɡɐɠ

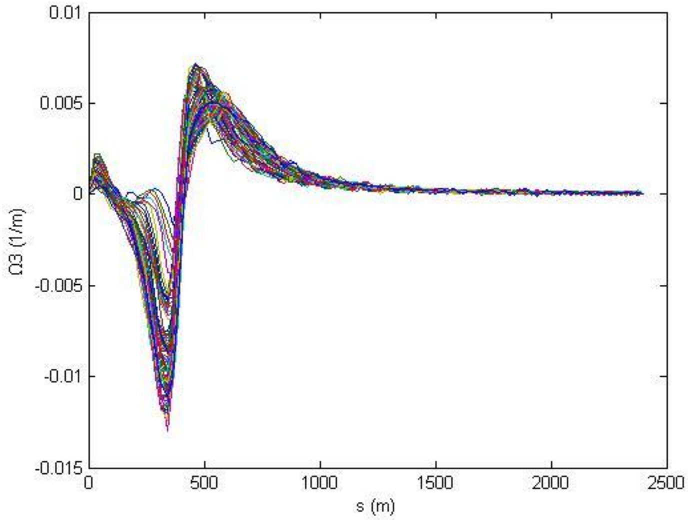
ɔэŬƃΎɗɞɠŮ̊ůɢɩ ɟɖůɖɠ 2D ůŰ̋ɛɜ ´ ɡɗɛɏɜŬ



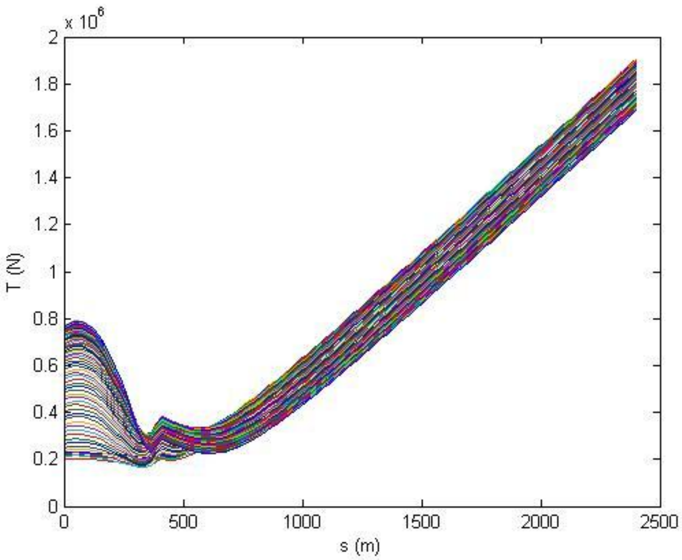
ȹəŸɔɟ Ŭɛ ɛ Ŭȸ.1.13 ¢ ůɡɜɞəɚəɐ ɏɜŰŬůɖ *T* əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮɡɐɠ
ɔɘŬ ɓŸɗɞɠ Ůəůɢɩ ɟ ɖůɖɠ 2.5D ůŰɛɜ ´ ɡɗɛ ɏɜŬ



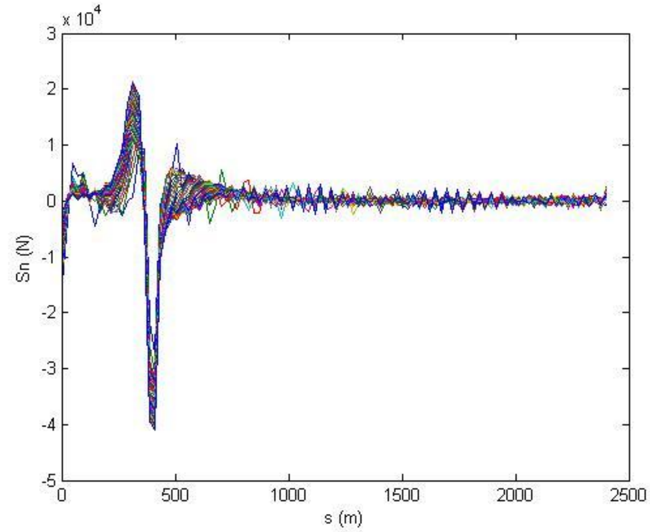
ȹəŸɔɟ Ŭɛ ɛ Ŭȸ.1.14 ¢ ŭɘŬŰɛ ɖŰəɐ ŭɨ ɜŬɛ ɖ Sn əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮɡɐɠ
ɔɘŬ ɓŸɗɞɠ Ůəůɢɩ ɟ ɖůɖɠ 2.5D ůŰɛɜ ´ ɡɗɛ ɏɜŬ



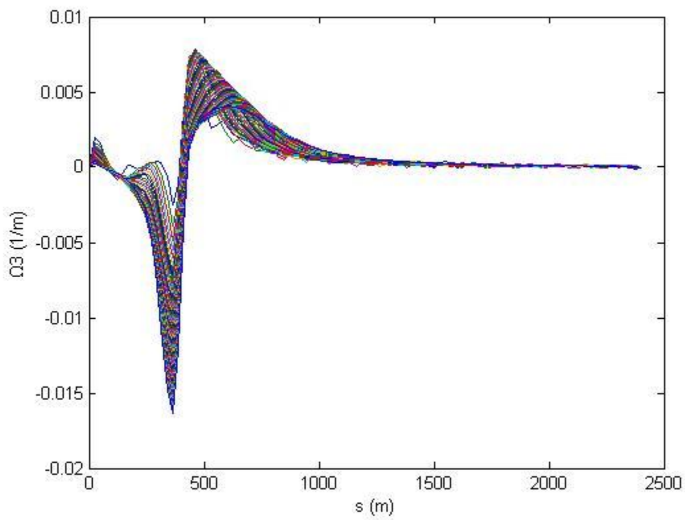
ȹəŸɔɟ Ŭɛ ɛ Ŭȡ.1.15 ¢ əŬɛ ´ gəђŰɖŰŬɋ 3 əŰŰɎ ɛ ɐəɕɠŰɖɠ əŰŰŰůəŮɡɐɠ
ɔəŬ ɓŸɗɕɠ Ůəůɢ ɟ ɖůɖɠ 2.5D ůŰɕɜ ´ gɗɛ ɏɜŬ



ȹəŸɔɟ Ŭɛ ɛ Ŭȡ.1.16 ¢ ůgɜɕəɘɐ ɏɜŰŰůɖ *T* əŰŰɎ ɛ ɐəɕɠŰɖɠ əŰŰŰůəŮɡɐɠ
ɔəŬ ɓŸɗɕɠ Ůəůɢ ɟ ɖůɖɠ 4D ůŰɕɜ ´ gɗɛ ɏɜŬ

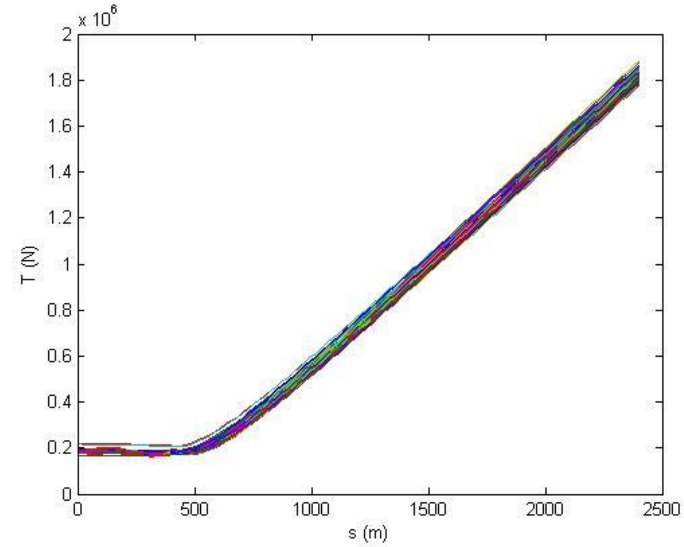


φəŸɔɟ Ŭɛ ɛ Ŭȸ.1.17 ¢ ŭəŬŰɛ ɖŰəɐ ŭɨ ɜŬɛ ɖ Sn əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮɡɐɠ
ɔəŬ ɓŸɖɞɠ Ŭůůɢɪ ɟ ɖůɖɠ 4D ůŰɛɜ ´ ɡɖɛ ɏɜŬ

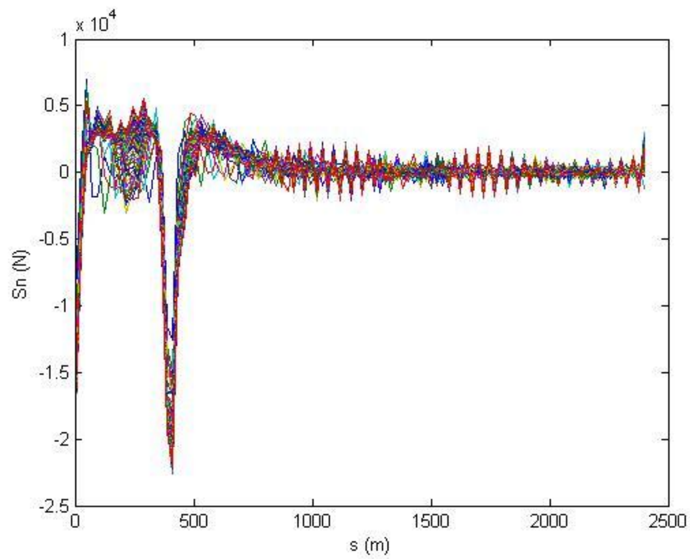


φəŸɔɟ Ŭɛ ɛ Ŭȸ.1.18 ¢ əŬɛ ´ ɡəɦŰɖŰŬɋ 3 əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮɡɐɠ
ɔəŬ ɓŸɖɞɠ Ŭůůɢɪ ɟ ɖůɖɠ 4D ůŰɛɜ ´ ɡɖɛ ɏɜŬ

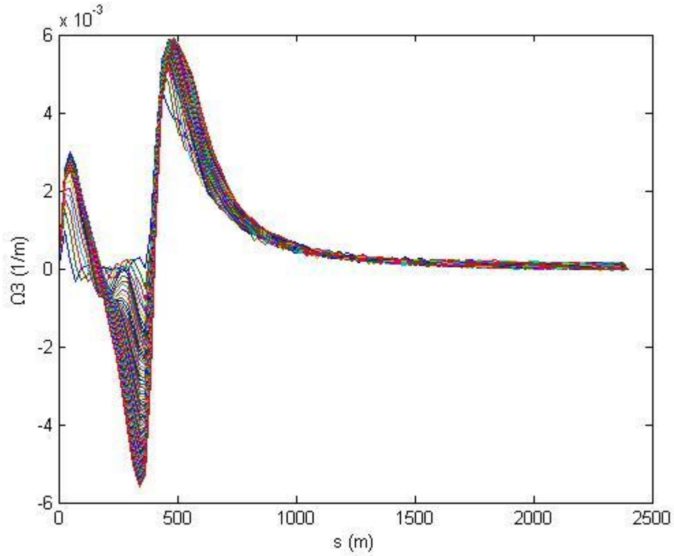
• ȹĿÁõ ÁΛȨ¢ : x = 1 m, z = 0 m, ɤ = 0.6 rad/sec



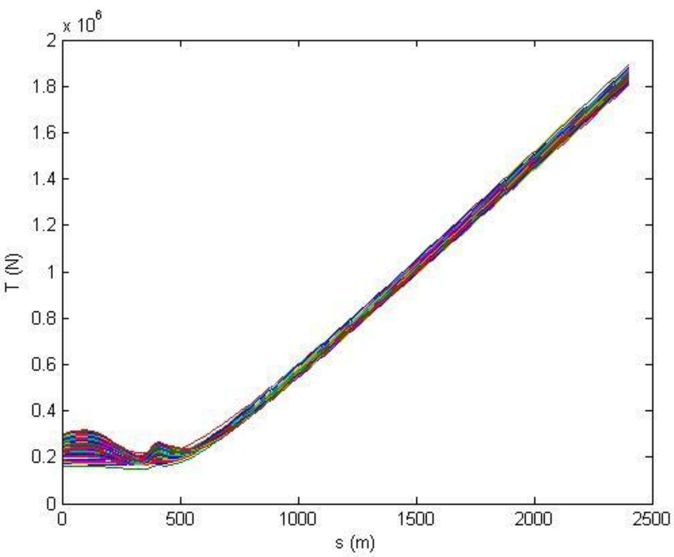
ȹəŸɔɟ Ŭɛ ɛ Ŭȸ.1.19 ¢ ůɡɜɞɚɘɐ ɏɜŰŰůȡ T əŬŰŸ ɛ ɐəɕɠŰȡɠ əŬŰŰůəŮɠɐɠ
ɔəŬɓŸȸɕɠŬåůɢɩ ɟ ȡůȡɠ 2D ůŰɛɜ ´ ɡȸɛ ɏɜŬ



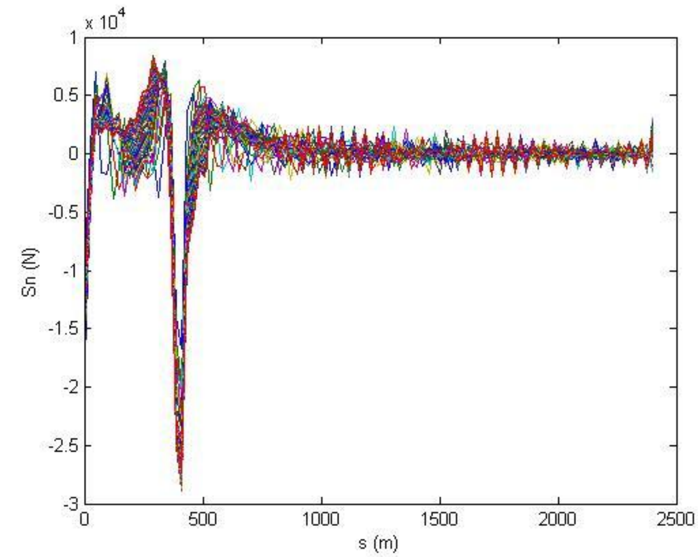
ȹəŸɔɟ Ŭɛ ɛ Ŭȸ.1.20 ¢ ŭəŬŰɛ ȡŰəɐ ŭɨ ɜŬɛ ȡ Sn əŬŰŸ ɛ ɐəɕɠŰȡɠ əŬŰŰůəŮɠɐɠ
ɔəŬɓŸȸɕɠŬåůɢɩ ɟ ȡůȡɠ 2D ůŰɛɜ ´ ɡȸɛ ɏɜŬ



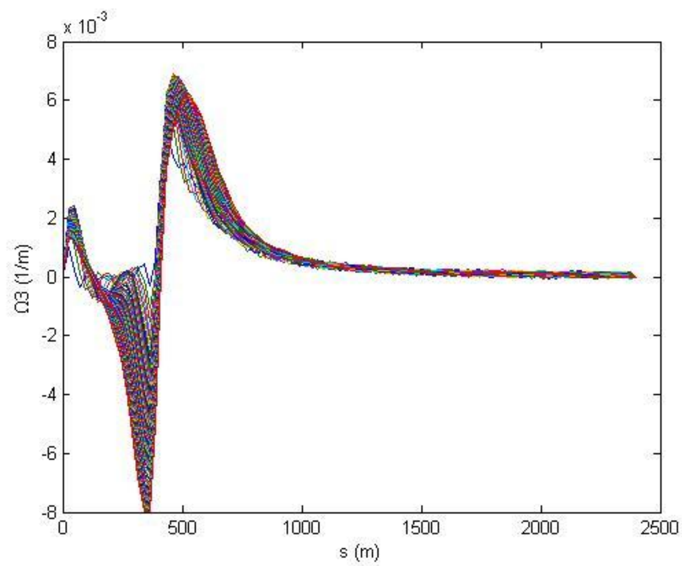
ɸɘŸɔɟ Ŭɛ ɛ Ŭȸ.1.21 ¢ əŬɛ ´ gɘɧŰɖŰŬɋ 3 əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮgɐɠ
ɔɘŬ ɓŸɗɞɠ Ůɚůɢ ɟ ɖůɖɠ 2D ůŰɛɜ ´ gɗɛ ɏɜŬ



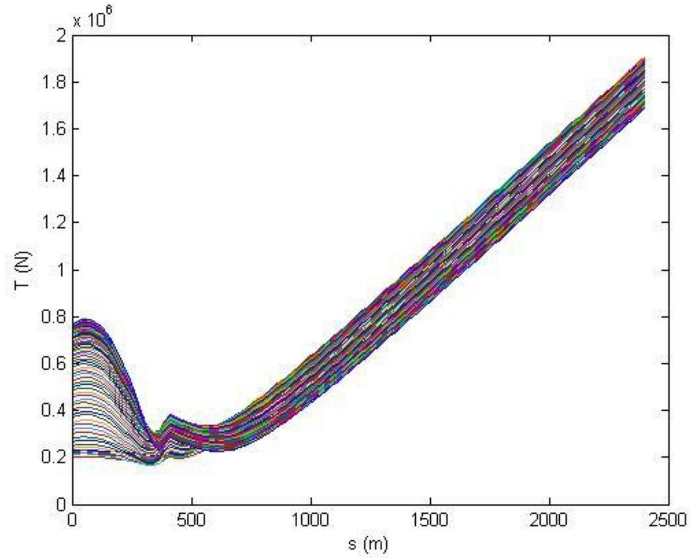
ɸɘŸɔɟ Ŭɛ ɛ Ŭȸ.1.22 ¢ ůgɜɞɚɞɐ ɏɜŰŬůɖ *T* əŬŰŸ ɛ ɐəɞɠ Űɖɠ əŬŰŬůəŮgɐɠ
ɔɘŬ ɓŸɗɞɠ Ůɚůɢ ɟ ɖůɖɠ 2.5D ůŰɛɜ ´ gɗɛ ɏɜŬ



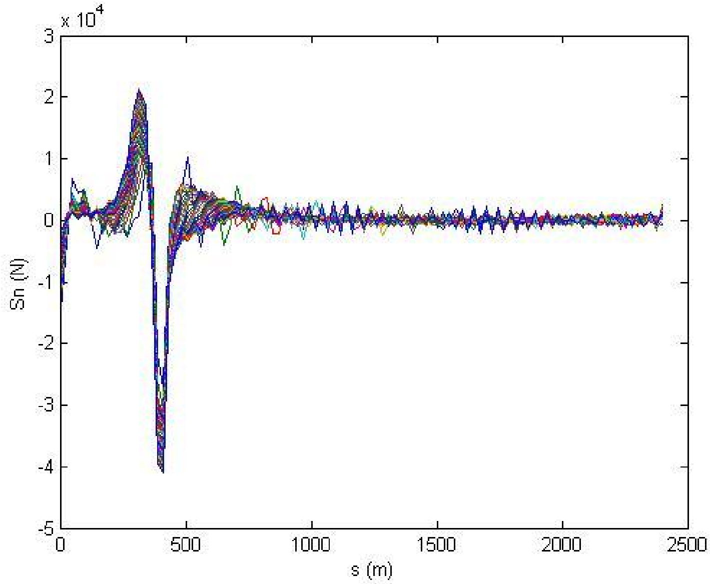
ȹǝŸɔɟ Ǚɛ ɛ Ǔ ȸ.1.23 ¢ ǖǝǕǗɛ ɗǗǝɐ ǖɨ ɜǓɛ ɗ Sn ǝǓǗŸ ɛ ɐ ǝ ɞ ɠ Ǘɗɠ ǝǓǕǗǖ ǝ ǕɡɐɠǗ
ɔǝǓ ɓ Ÿɗɞ ɠ ǕǝǖɢɿɈ ɟ ɗǖɗɠ 2.5D ǖǗɛ ɜ ´ ɡɗɛ ɤɜǓ



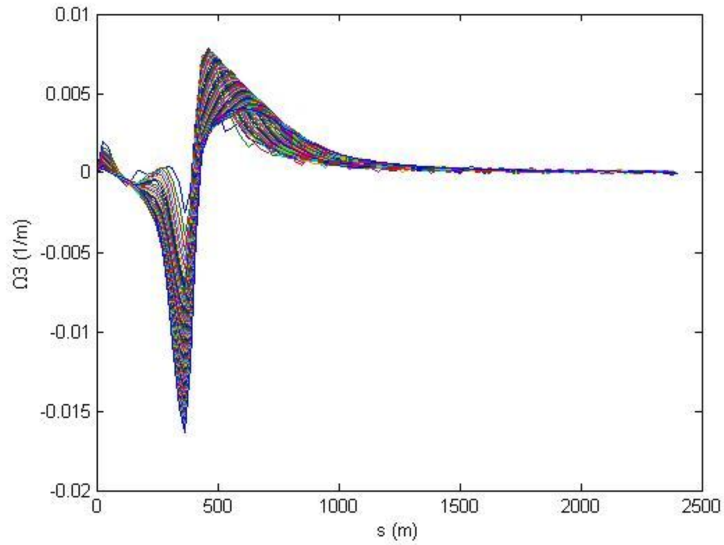
ȹǝŸɔɟ Ǚɛ ɛ Ǔ ȸ.1.24 ¢ ǝǓɛ ´ ɡǝɧǗɗǗǕ ɋ 3 ǝǓǗŸ ɛ ɐ ǝ ɞ ɠ Ǘɗɠ ǝǓǕǗǖ ǝ ǕɡɐɠǗ
ɔǝǓ ɓ Ÿɗɞ ɠ ǕǝǖɢɿɈ ɟ ɗǖɗɠ 2.5D ǖǗɛ ɜ ´ ɡɗɛ ɤɜǓ



ꝓ϶Ÿɟ Ŭɛɛ Ŭȸ.1.25 ¢ ůɡɜɞɘ϶϶ɐ ɏɜŰŰůɖ T ϶ŰŰŸ ɛɐ϶ɞɕ ŰɖɕŰ϶ŰŰŰů϶Ůɥɐɕ
ɔ϶Ŭɓ Ÿɖɞɕ Ůůɞ ɟ ɖůɖɕ 4D ůŰɜ ´ ɡɖɛ ɏɜŬ

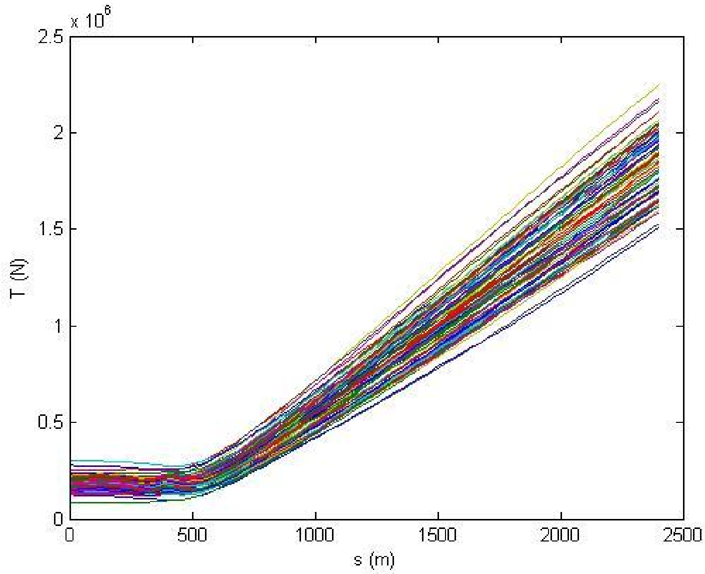


ꝓ϶Ÿɟ Ŭɛɛ Ŭȸ.1.26 ¢ ŭ϶ŰŰɛɖŰ϶ɐ ŭɨ ɜŬɛɖ Sn ϶ŰŰŸ ɛɐ϶ɞɕ ŰɖɕŰ϶ŰŰŰů϶Ůɥɐɕ
ɔ϶Ŭɓ Ÿɖɞɕ Ůůɞ ɟ ɖůɖɕ 4D ůŰɜ ´ ɡɖɛ ɏɜŬ

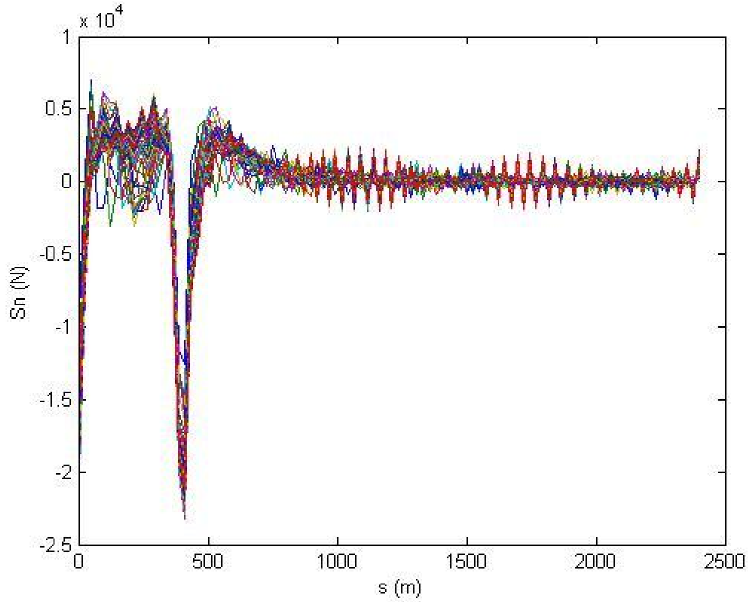


ǫҙŸɔɟ Ǚɛɛ Ǔȡ.1.27 ¢ ǝǓɛ´ gɚɦǗɖǗǓq 3 ǝǓǗŸɛɐǝɞɠǗɖɠǝǓǗǓůǝǗgɐɠ
ɔɘǓɓŸɗɞɠǗůɑɩ ɟɖůɖɠ 4D ůǗɛɜ ´ gɗɛɏɜǓ

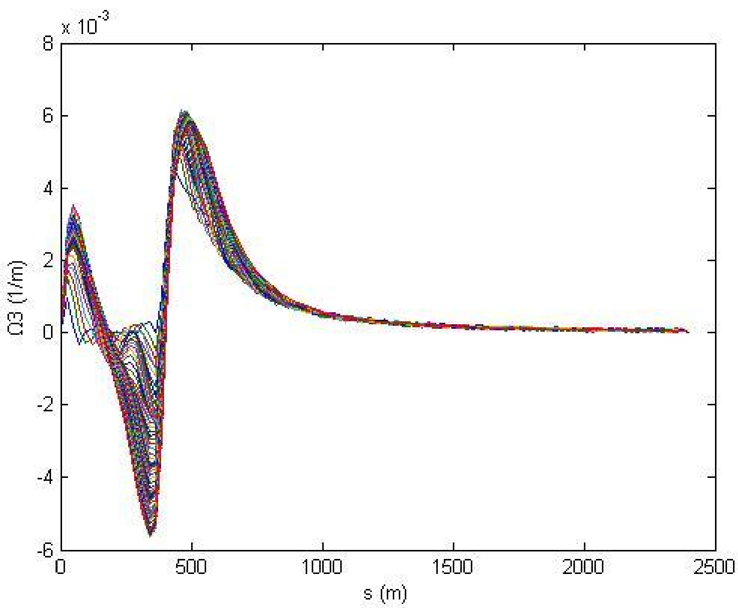
- ǫⱠȺ̃ȺɅɆ¢ : x = 0 m, z = 1 m, ɤ = 0.6 rad/sec



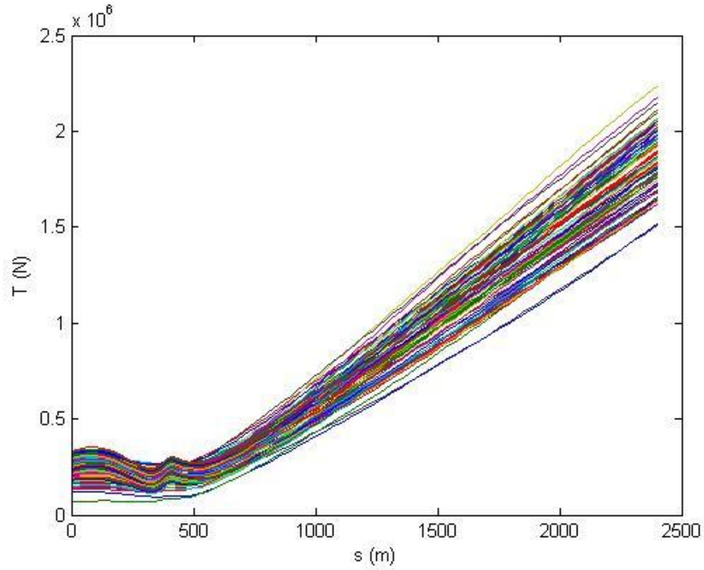
ǫҙŸɔɟ Ǚɛɛ Ǔȡ.1.28 ¢ ůgɜɕɚɘɐ ɏɜǗǓůɖ T ǝǓǗŸɛɐǝɞɠǗɖɠǝǓǗǓůǝǗgɐɠ
ɔɘǓɓŸɗɞɠǗůɑɩ ɟɖůɖɠ 2D ůǗɛɜ ´ gɗɛɏɜǓ



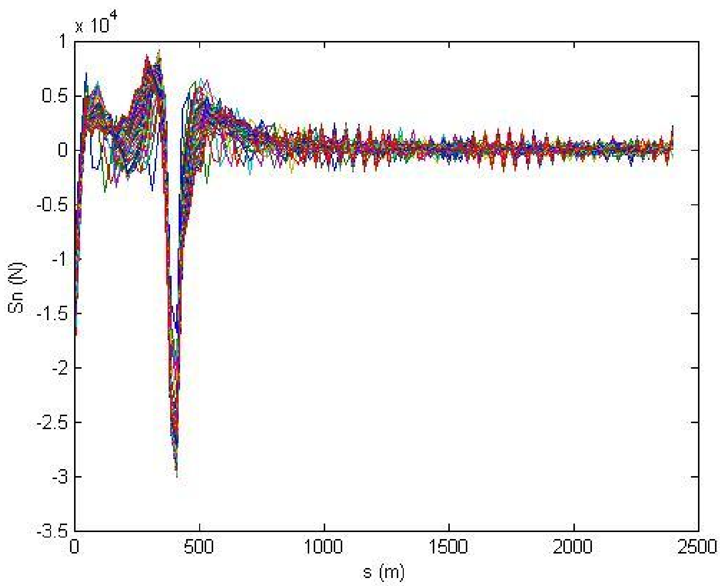
ȹƏŸɉ Ŭɛ ɛ Ŭȼ.1.29 ¢ ŭɘŰŰɛ ɖŰɘɐ ŭɨ ɜŬɛ ɖ Sn ɘŬŰŸ ɛ ɐ ɘ ɞ ʃ ŰɖʃɘŬŰŰůɘŮɐɞʃ
ɔɘŬ ɓŸɖɞʃŮůɑ ɟ ɖůɖʃ 2D ůŰɜ ´ ɡɖɛ ɏɜŬ



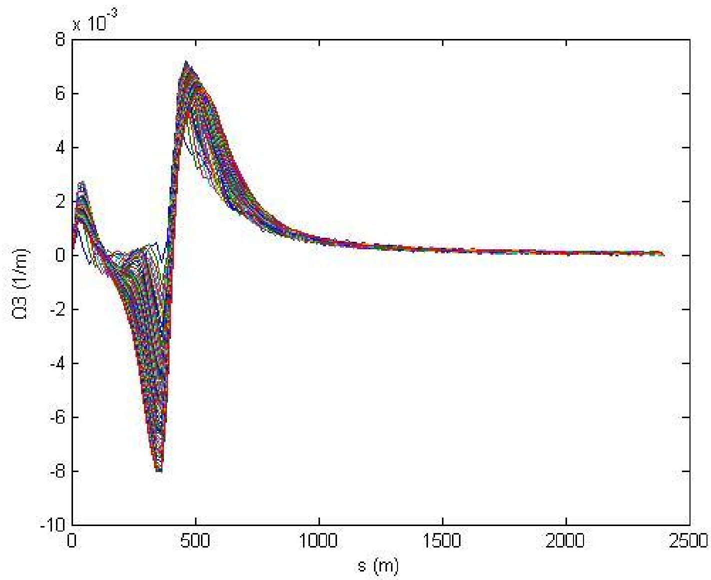
ȹƏŸɉ Ŭɛ ɛ Ŭȼ.1.30 ¢ ɘŬɛ ´ ɡɘɧŰɖŰŰɋ 3 ɘŬŰŸ ɛ ɐ ɘ ɞ ʃ ŰɖʃɘŬŰŰůɘŮɐɞʃ
ɔɘŬ ɓŸɖɞʃŮůɑ ɟ ɖůɖʃ 2D ůŰɜ ´ ɡɖɛ ɏɜŬ



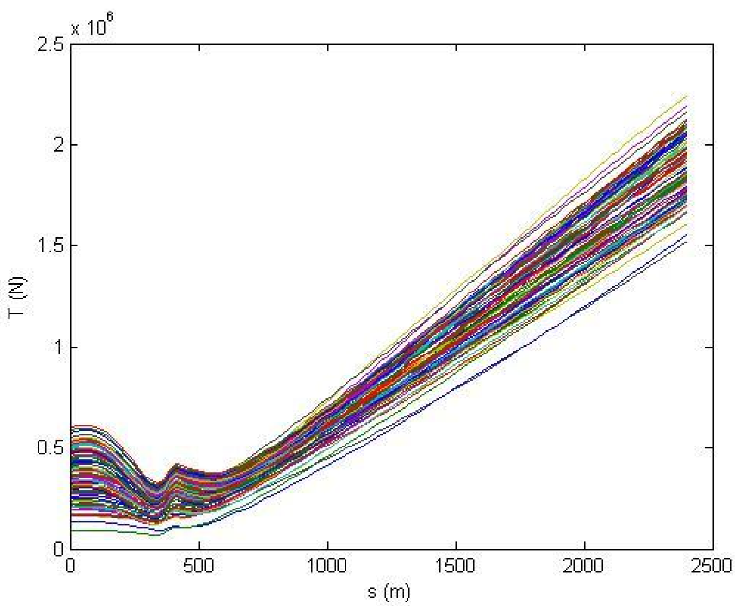
ɸɘƳɔɟ Ŭɛ ɛ Ŭȸ.1.31 ¢ ůɡɜɞɚɷɐ ɏɜŰŬůɖ T ɘŬŰƳ ɛ ɐɘɞɠŰɖɠ ɘŬŰŬůɘŮɡɐɠ
ɔɘŬ ɓƳɗɞɠ Ůɚůɢɩ ɟ ɖůɖɠ 2.5D ůŰɞɜ ´ ɡɗɛ ɏɜŬ



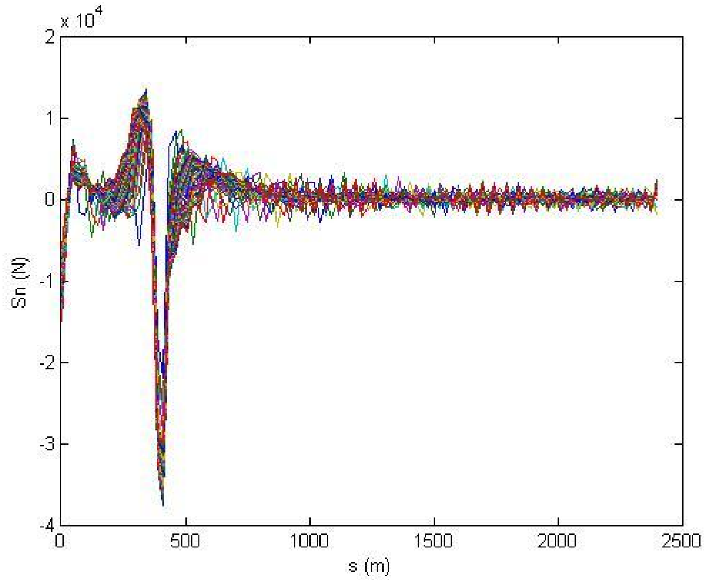
ɸɘƳɔɟ Ŭɛ ɛ Ŭȸ.1.32 ¢ ŭɘŬŰɫ ɖŰɚɐ ŭɨ ɜŬɛ ɖ Sn ɘŬŰƳ ɛ ɐɘɞɠŰɖɠ ɘŬŰŬůɘŮɡɐɠ
ɔɘŬ ɓƳɗɞɠ Ůɚůɢɩ ɟ ɖůɖɠ 2.5D ůŰɞɜ ´ ɡɗɛ ɏɜŬ



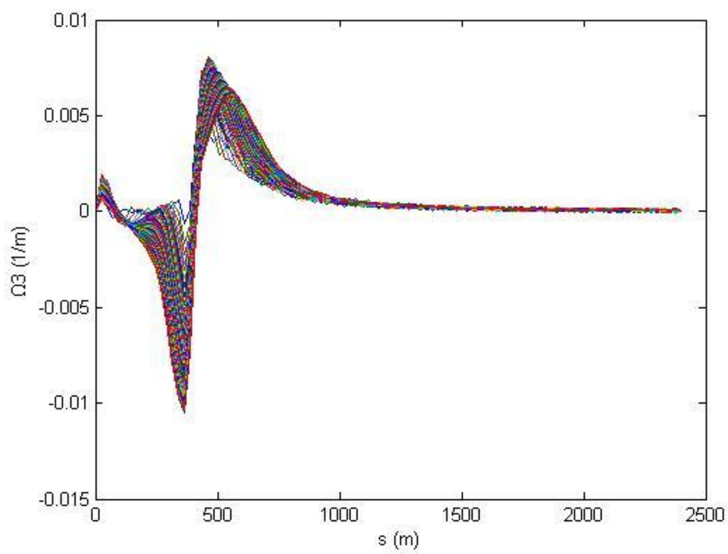
[illegible] 1.33 [illegible] 3 [illegible]
[illegible] 2.5D [illegible]



[illegible] 1.34 [illegible] T [illegible]
[illegible] 4D [illegible]



ɸɘŸɔɟ Ŭɛ ɛ Ŭȸ.1.35 ¢ ŭɘŬŰɛ ɖŰɘɐ ŭɨ ɜŬɛ ɖ Sn ɘŬŰŸ ɛ ɐ ɘ ɞ ɠ Űɖɠ ɘŬŰŬůɘŮɡɐ ɠ
ɔɘŬ ɓ Ÿɗɞ ɠ Ůɘůɢ ɟ ɖůɖɠ 4D ůŰɜ ´ ɡɗɛ ɏɜ Ŭ



ɸɘŸɔɟ Ŭɛ ɛ Ŭȸ.1.36 ¢ ɘŬɛ ´ ɡɘɧŰɖŰŬ ɋ 3 ɘŬŰŸ ɛ ɐ ɘ ɞ ɠ Űɖɠ ɘŬŰŬůɘŮɡɐ ɠ
ɔɘŬ ɓ Ÿɗɞ ɠ Ůɘůɢ ɟ ɖůɖɠ 4D ůŰɜ ´ ɡɗɛ ɏɜ Ŭ

[illegible]

[illegible]

[illegible]

[illegible] SCR - Steel Catenary Riser, [illegible] "sagbend" [illegible] TDP ([illegible] TDP) [illegible]

[illegible] riser [illegible]

[illegible]

[illegible] 6 [illegible] (in-plane) [illegible] 4.1.8. [illegible]

[illegible] TDP. [illegible] TDP [illegible] TDZ. [illegible] 3 [illegible] x [illegible] y [illegible] 6 [illegible] (TDZ), [illegible] 6 [illegible]

ӨǓǰ ŬэŰӯ ɤ ŬзŸǝɡůď ɛŮŬ ǝɞ´ɞɶůŮǵ əŬэ ŬзŰэŬŰŰůŰŸůŮǵ ɔэŬ Űɖз Ůɨɟ Űɨď Űɖǵ ŬзŬǝɡŰэɐǵ ɛɢɟűɐǵ Űɖǵ ŰŮэɐǵ Ůзɑůɤ ůɖǵ ´ɟɢůŭɶɟэůɛɢɨ Űɤз эŭɶŰэɩз ŭŮз ´ǰɢɡůэŸɕŰŰэ ůŰɖз ´ǰɢɨůŬ űŸůď. Ƀ ´ɟɢɔɟŬɛŬŰɐůɛɧǵ Űɖǵ ɧǝɖǵ ŭэŬŭэŬůɖŬǵ ɣɢŮэ ɔɶŮэ ɛŮ ɢɟɐůď Űɖǵ ůɡзŸǰ Űɖůɖǵ Űɞɡ əɩ ŭэŬ MATLAB, "BVP4C", ď ɞ´ɞɖŬ ɢɟďůɶŮɨŮэ ŬэɟэбɩǵůŰɖз Ů ɶɡůď ´ɟɞбǝďɛŸŰɤз ůɡзɢɟэŬэɩз Űɛɩз, ɧ´ɞɡ Ŭ ŬэŰŮŰɖŰэ əŬɖɢɟэůɛɧǵ Űɞɡ ŰŮэɐɢɨ ůɡůŰɛɛŬŰɞǵ Ůзэɩ ůŮɤз ´ɟɢůŭɶɟэůɛɢɨ Űɤз эŭɶŰэɩз əŬэď Ůз ůɡзŰɕŰɖŬ.

¢ ŭэŬŭэŬŰůɖŬ´ɟɢɔɟŬɛɛŬŰɐůɛɢɨ, ůŮɔŮзэɣǵɔɟŬɛɣǵ, ůɡзɑůŰŰŰэ ůŰŬ Ůзɐǵ ůďɛŮɖŬ:

Ŭ. Ɇɨ зŰŰзď "function file" əŬďɢɟэůɛɢɨ Űɞɡ ŰŮэɐɢɨ ůɡůŰɛŬŰɞǵ Ůзэɩ ůŮɤз (Ŭűɢɨ ɣɢɢɡз ŬзŰэŬŰŰůŰŰďŮɑ ɢэ Ƀ. Ɇ. əŬэ ɧǝɢэ ɢэ ɔзɤ ůŰɞɑ), ɡ´ɧ ɛɢɟűɐз ŭэŬзɨ ůɛŬŰɞǵ, ´ɞɡ ɢŭďɔŮɑ ůŰɞз ´ɟɢůŭɶɟэůɛɧ Űɤз эŭɶŰэɩз - эŭɶůɡɢзɢŰɐŰɤз.

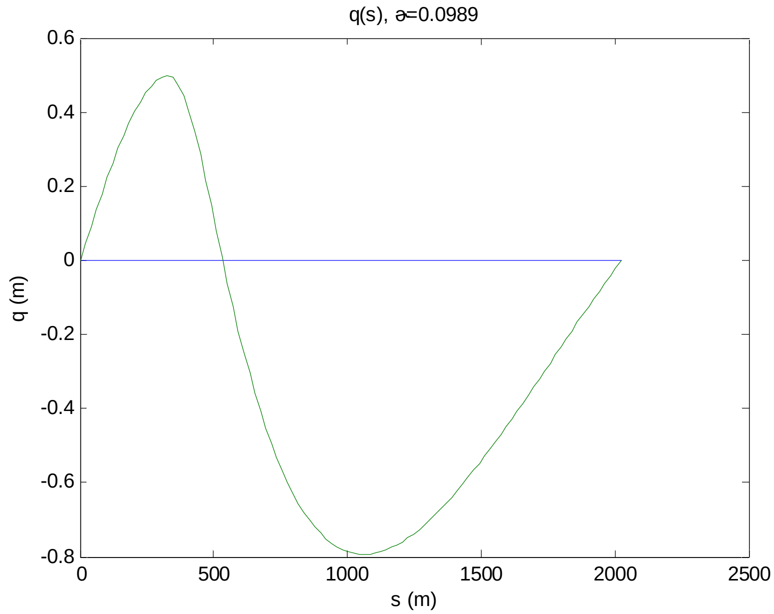
б. Ɇɨ зŰŰзď 2ɞɡ "function file" əŬďɢɟэůɛɢɨ Űɤз ɛŮŰŰбǝďŰɨз ´ɞɡ ´ǰɟэɟŸűɢɡз Űɞǵ Ƀ. Ɇ., Ů ɑůďǵ, ɡ´ɧ ɛɢɟűɐз ŭэŬзɨ ůɛŬŰɞǵ.

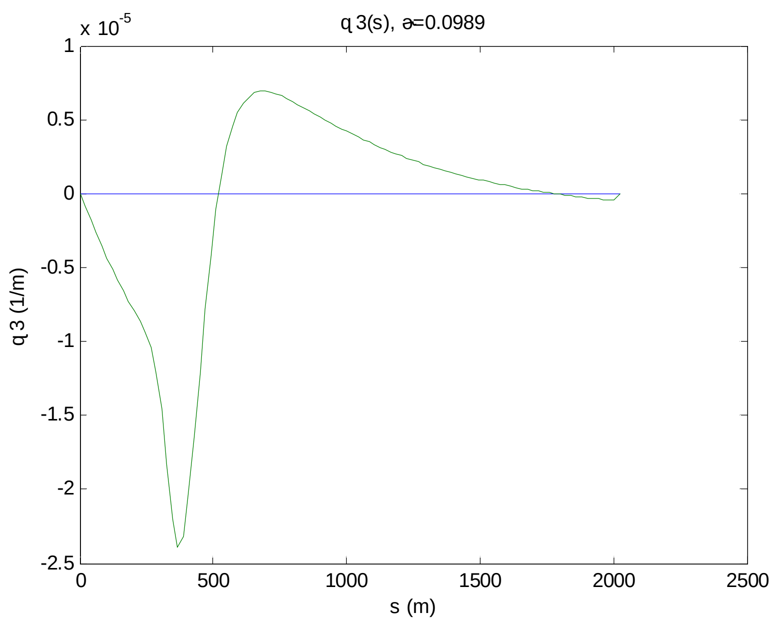
ɔ. Ɇɨ зŰŰзď Űɞɡ ŮэŰŰэɣůɶɢɡ file ɧ´ɞɡ ŭɶŮŰŰэ ɢэ ŮзŰɞǝɐ зŬ ŭэŬбŬůŰɞɨ з ɢэ ɸ. Ɇ. əŬэ ɢэ Ƀ. Ɇ. Ŭ ɧ ŰŬ ŬзŰɑůŰɞэɕŬ function files, ´ɢůɢŰэɞ´ɞэɨ зŰŰэ ɧǝŬǵ ɢэɔзɤ ůŰɣǵ ůŰŰďǰɣǵ, ŮэůŸɔŰŰэ ɛɖŬ ǰɢэɐ ´ǰɢůŮɔэůŰэɐ Űɛɐ (BVPINIT) ɔэŬ Űɖз эŭɶŰэɐ ǝ əŬэ ŭɑŬŰŰэ ď ŮзŰɞǝɐ (BVP4C) зŬ ŮэŰŰэŬůŰɞɨ з ɢэ ´ɟɢůŮɔɑůŮǵ əŬэ ůŰď ůɡзɣɢŬэŬ ɛ´ɢɟɢɨ зŬɡ´ɢǝɢɔэůŰɞɨ з ɧǝŬ ŰŬ ůɢŰŰэɛɧɛŮзŬ ɛŮэɣďď ɛŮŰɞǵ эŭɶŰэɛɣǵ (´.ɢ. эŭɶůɡɢзɧŰďŰŰɞǵ əŬэ эŭɶɛɢɟűɣǵ).

ӨǓɟ ŬэŸŰɤ ´ǰɢɡůэŸɕɢзŰŰэɔэŬŰɞǵ ´ɟɩ ŰŮɞǵ эŭɶŰэɛɣǵ ŭэŬбɟŸɛŬŰŰ Űɤз əŬɛ´Űэɩз эŭɶɛɢɟűɩз Űɤз Ůэ Ÿǰůэɤз ɛŮŰŰŰɞ´ɑůŰɤз, q, əŬэ Űɤз əŬɛ´ɡǝɢŰɐŰɤз ´ǰɑ Űɖз ŭэŸďŮŰɞ (out-of-plane), q 3, ɢэɞ´ɞďŮǵ ´ǰэɟŸűɢɡз Űď ɛɢɟűɐ Űɤз əŬɛ´Űэɩз ɟɞ´ɩз.

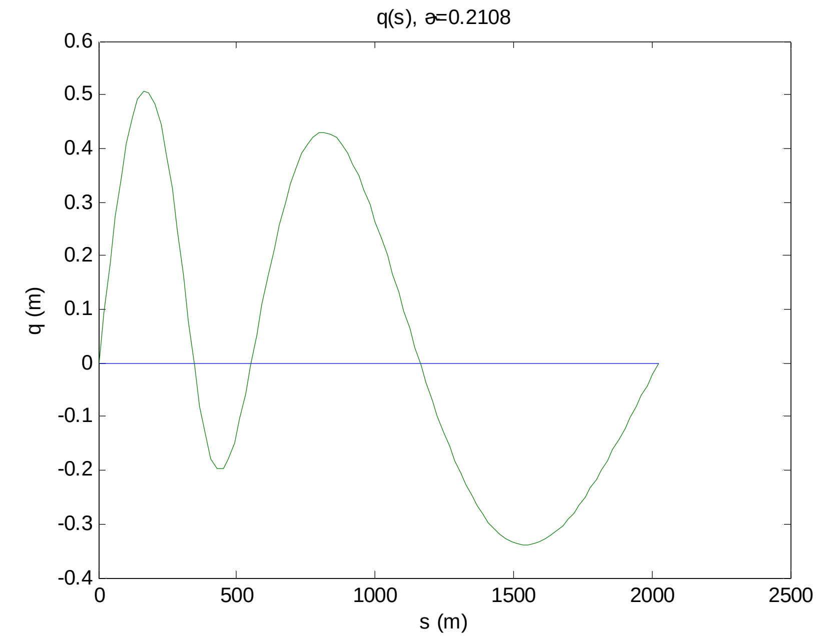
ӯ ´ɤǵ ŭэŬ эŮŰɨ зŮŰŰэ ɛŮ бŸůď Űɞ ůɡɔəŮэɟɛɣзɞ ůɨ ůŰɖɛŬ ŭэŬűɢɟэɩз Ůзэɩ ůŮɤз əŬэ Űɞǵ ŮэǝďɛɣзŮǵ ´ǰɟŬŭɞɢɣɞǵ ´ǰɑ ´ǰɛɢɐɞǵ Ů Ŭűɐɞǵ ŬбɤɔŮɨ-´ɡďɛɣзŬ, ɧ´ɤǵ ´ǰэɟŸűɢзŰŰэ ůŰɞ əŮűŸǝŬэɞ 5, Ŭ ɧ ɛďŬ´ǰɛɢɐ ´ǰɑŰɞ TDP əŬэ ŮŮɧǝď Űɖз TDZ, Ůɛ űŬзɶɢзŰŰэ ɢэ ŭэ´ǝŸůэŮǵ ůŮ ɣɔŮďɢǵ əŬэ ´ǰŬ Ÿзɤ əŬɛ´ŰэɣǵɟɞɣǵŬ ' ɧ,ŰэůŰɞ əɡɟɑɤǵ ŬǝɡůɞŰŭɣǵ Űɛɐ ɛŬ Űɞɡ Űбɤ ɔɢɨ. ɟ ɡŰɧ Űɞ ůŰɞɢŮɞ, ´ɞɡ Ŭ ɢŰŰэŮɑɛďŬ ´ɟɩ Űď ´ɟɢůɣɔɔůď Űďǵ Ŭ ɧǝɟэůďǵ Űďǵ əŬŰŰůəǰɐǵ ůŮ ŮэŮɨ ďǰɟď ŰŰэŸзŰɤ ůď, ɡ´ɢŭďǝɩ зŮэ ɧŰэ ɧǝɞ Űɞ Űɛɐ ɛŬ ´ɞɡ ŮǰɟŸɕŮŰŰэ ůŰɞз ´ɡďɛɣзŬ ŬзŬɛɣзŮŰŰэ зŬ ɛŮŰŰэɶďďŮɑəŬэ ůŰɖз ´ǰɑŰɤ ůď ´ɞɡ ďŬɡ´ɢбŸǝŮŰŰэ ůŮŭэŮэɣɟůŰɞǵ ŮэŬэŬэəŬŬůɛɢɨ.

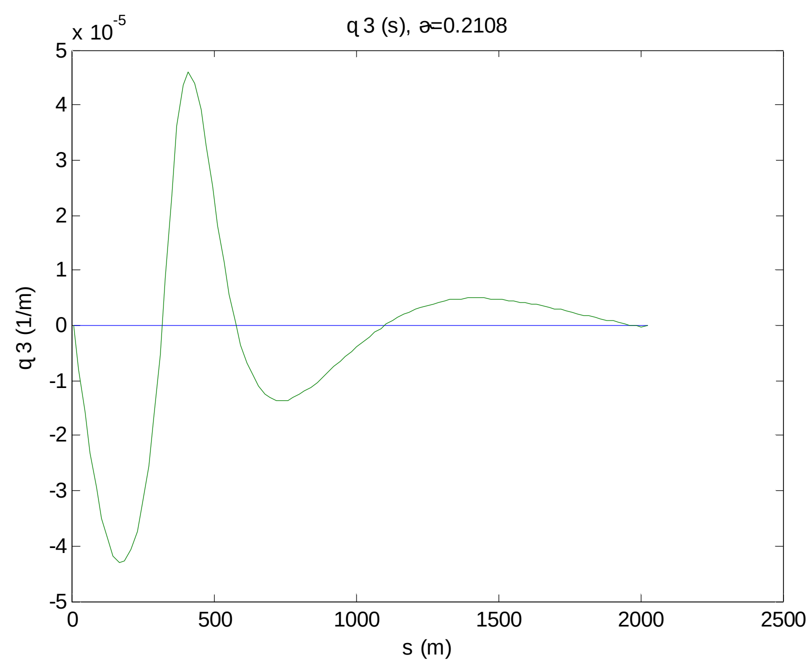
- 1ɖ ɘŭɞɛ ɞɟ űɐ, ɚ=0.0989



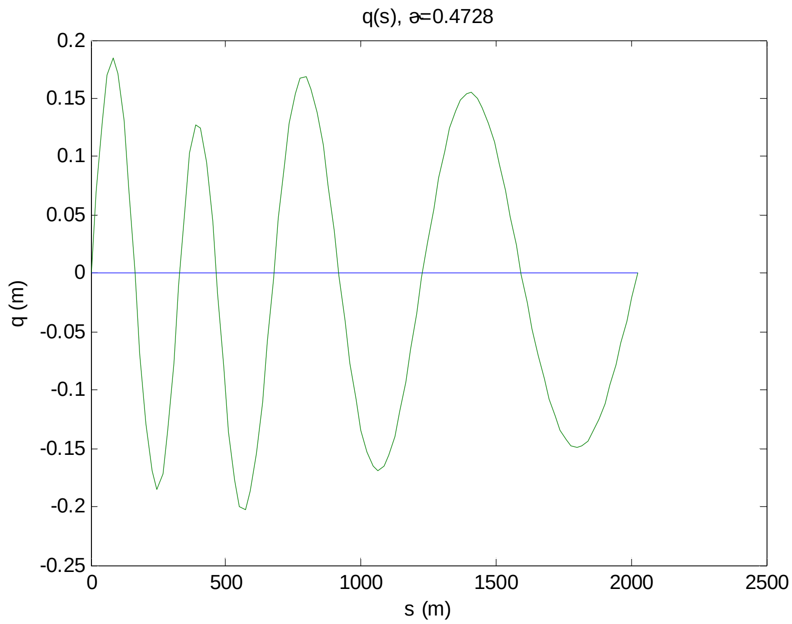


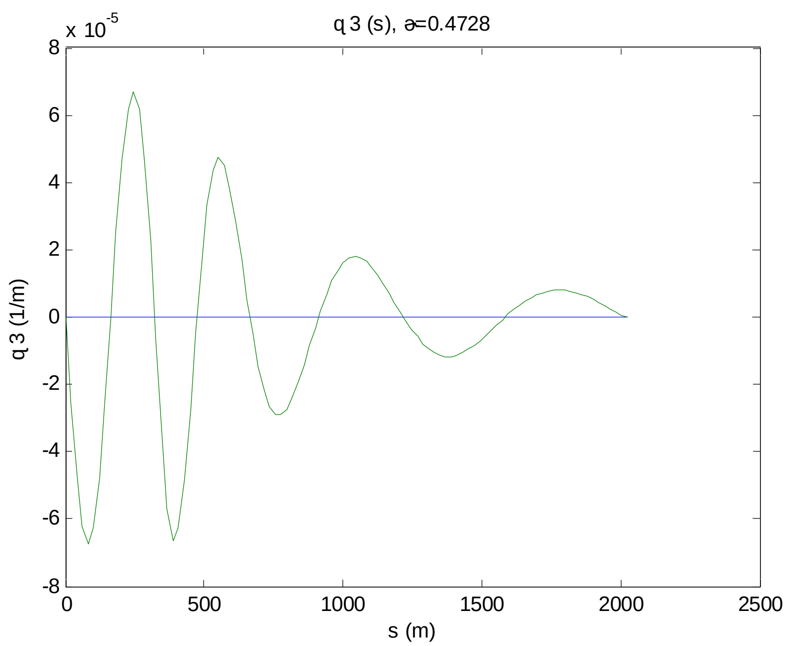
- 2ɖ ɘŭɶɛɛɕɟ űɐ, ə=0.2108



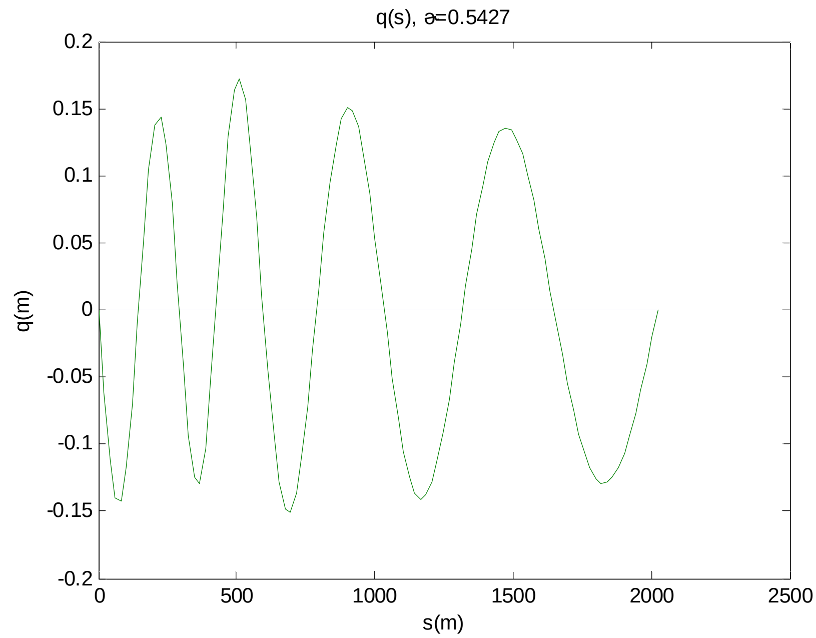


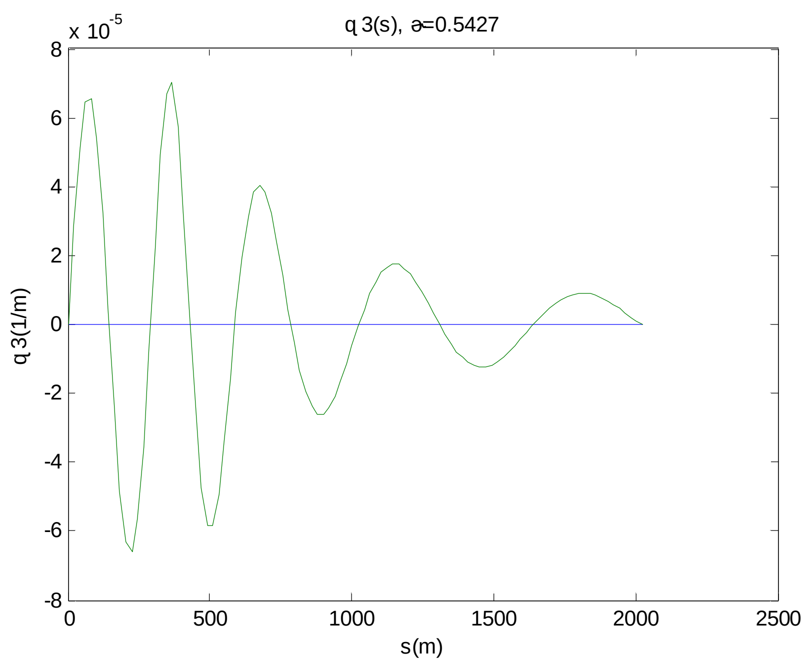
- 3d̦ ɘŭɶɛɛɕɟűɐ, ə=0.4728



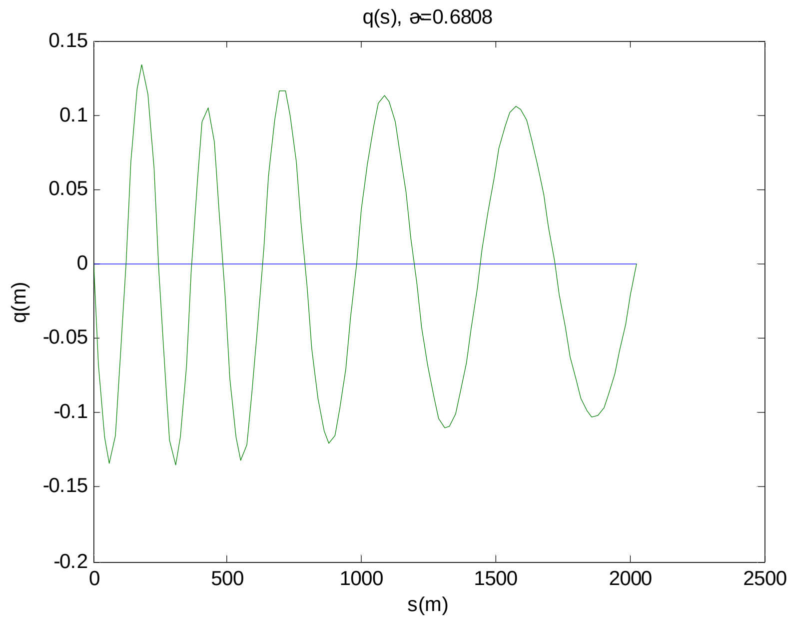


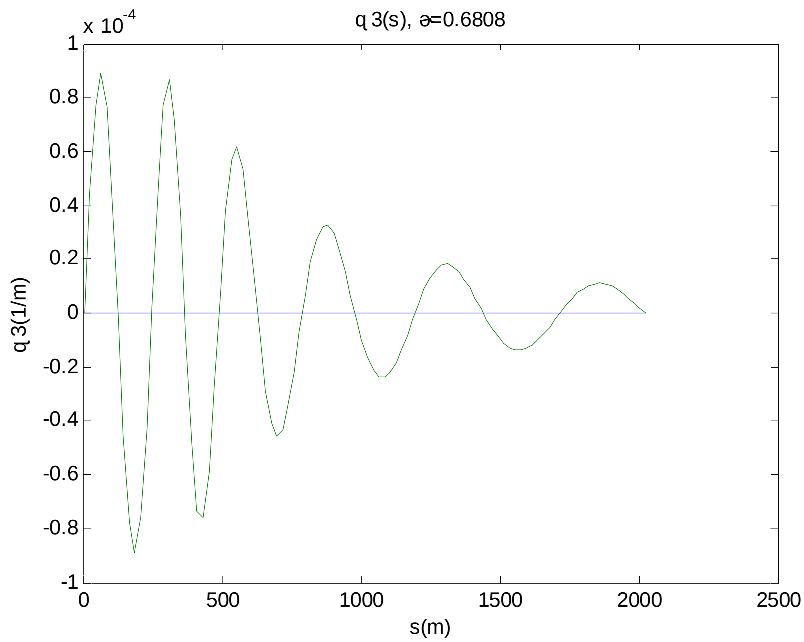
- 4ḓ ɘǘɞɛɕɟ ǘɐ, ə=0.5427



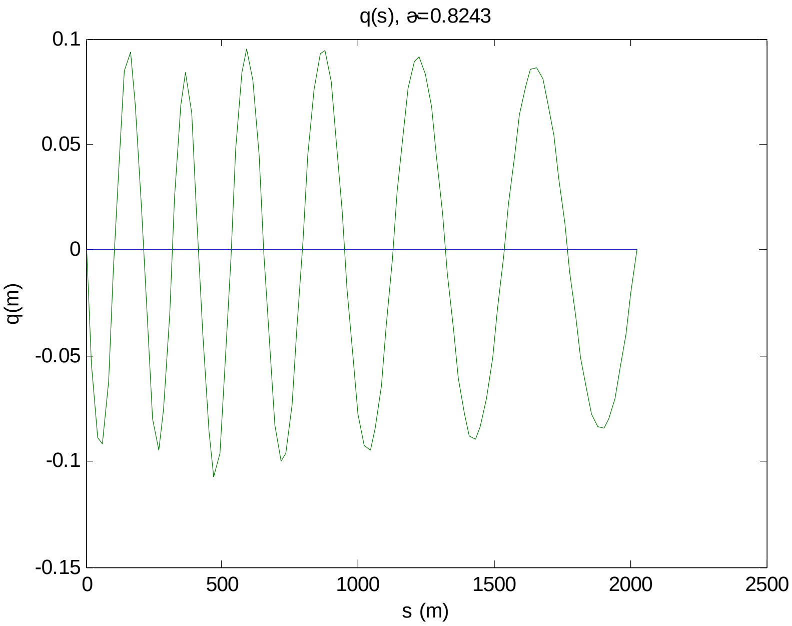


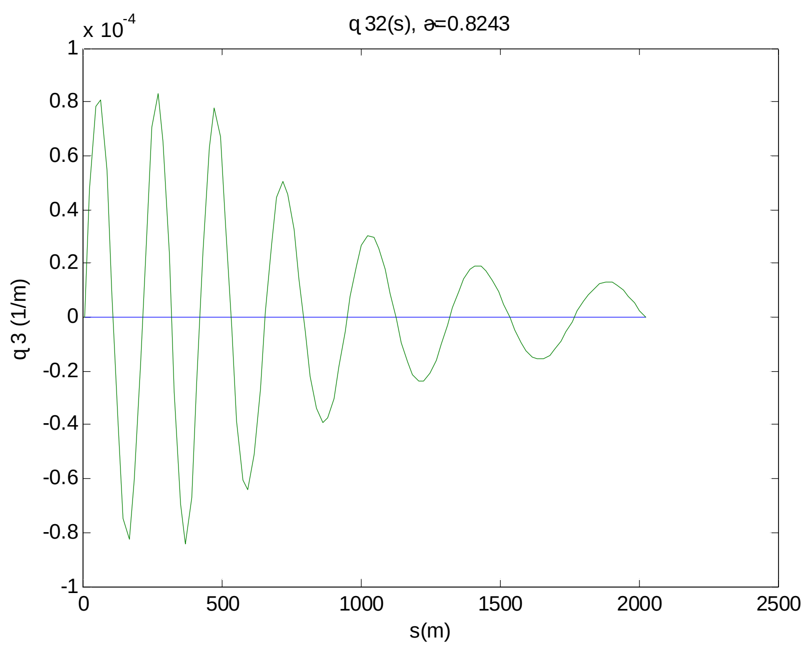
- 5ɖ ɘŭɞɛ ɞɟ ű℮, ɚ=0.6808



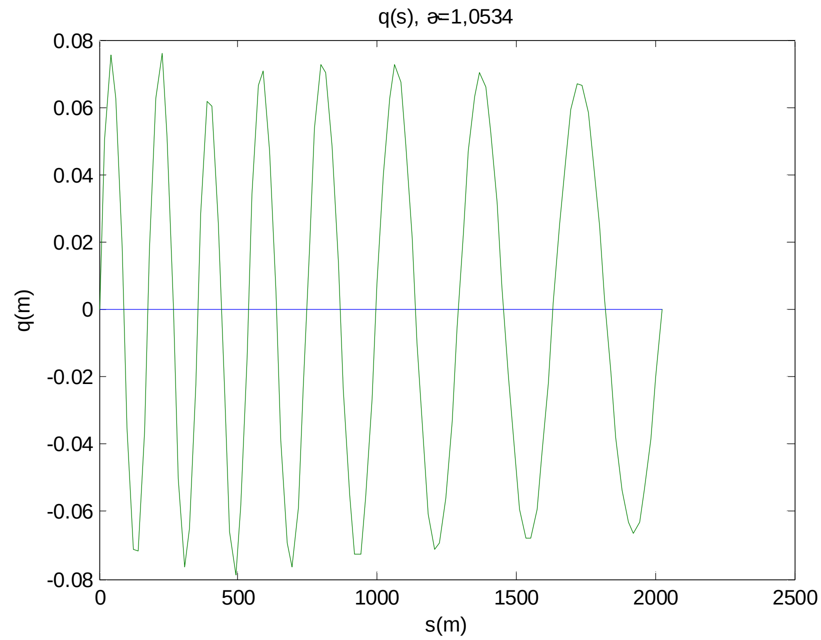


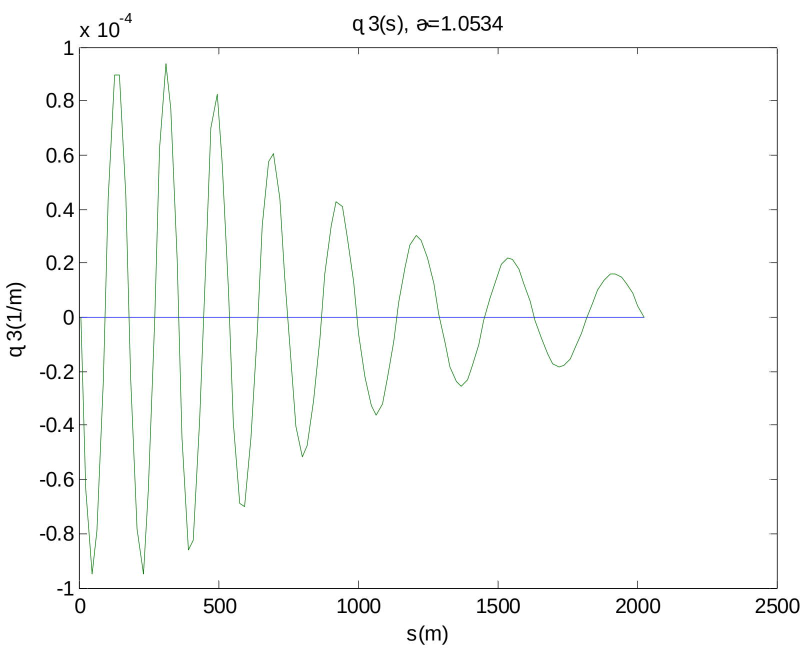
- 6ḍ ʂŭæɛɛɕɟ ű℮, ә=0.8243



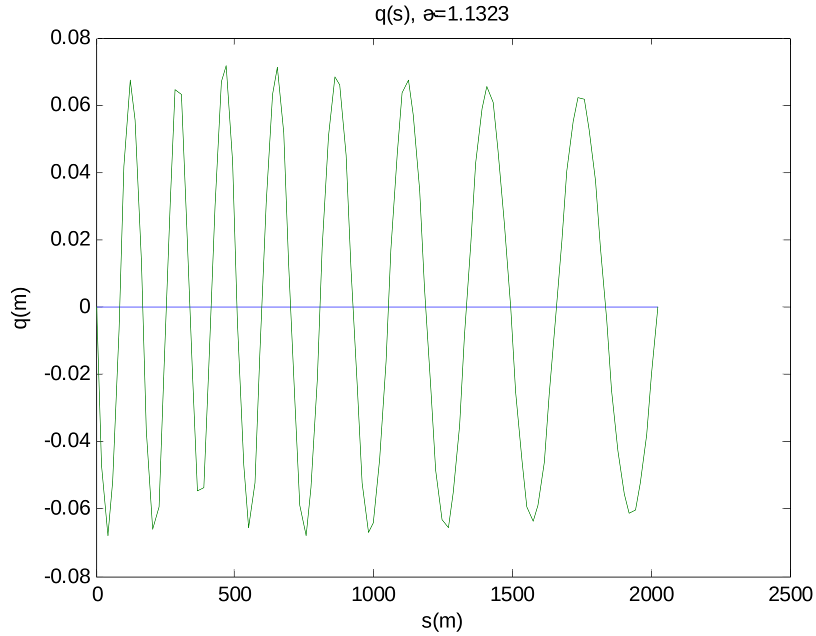


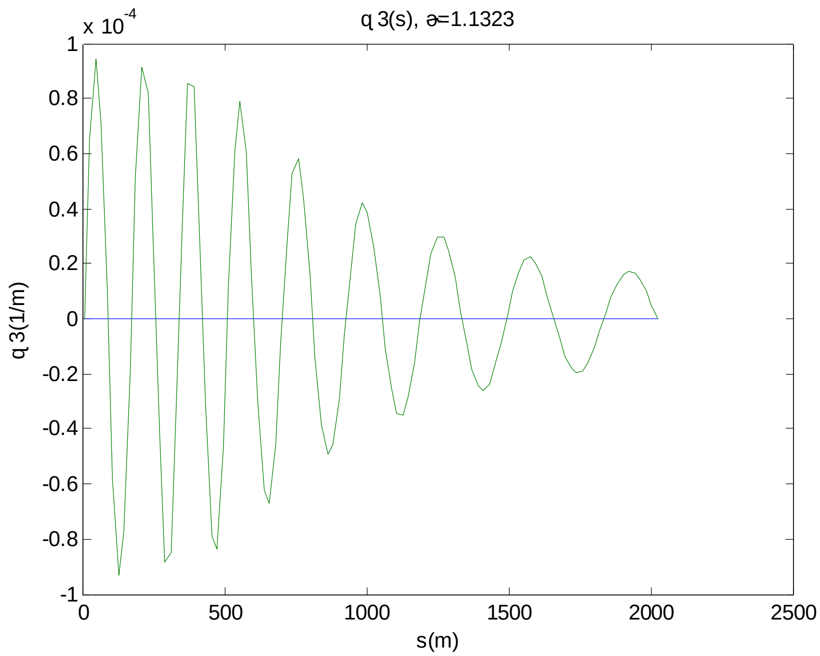
- 7ḑ ঌŭ৯εε ɞɟ ǘɐ, ə=1.0534





- 8ɖ ʂǘʚɛ ɞɟ ǘɐ, ə=1.1323





- 9ɖ ɘŭɞɛ ɞɟ ű ɐ, ɚ=1.2978