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Evaluation of the Soil Properties Effect on Upheaval Buckling of Subsea Pipelines

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ABSTRACT

Different parameters contribute on the upheaval buckling of subsea pipelines. Seabed is a surface that pipeline contact with it directly. So seabed is one of the most important parameters in the upheaval buckling of subsea pipeline. Subsea pipeline includes imperfection shape and characteristics of the seabed soil. In this paper, different soil types are considered for seabed and modeled with ABAQUS standard code. Seabed is modeled as a two-dimensional springs. The task of these springs is to react like soil against forces. The calculation of spring stiffness is based on standard code of American Lifelines Alliance. The critical stress increases due to the soil cohesion increasing. Soil cohesion is more effective parameter than soil angle friction of the soil. In this study, the effect of temperature difference is evaluated for different types of soil. 10 difference temperature is considered for this evaluation. 50 °C to 110 °C is the range of mentioned temperature. The effect of difference temperature on the upheaval buckling increases due to increasing of angle friction.

1. Introduction

Subsea pipelines are exposed to upheaval buckling due to high temperatures and pressure [1,2]. Many subjects affect pipeline conditions. The specifications of the space around the pipeline can be the most important factor affecting the risks that may occur to the pipeline [3]. The pipeline is surrounded by water and seabed. Hydraulic pressure is inserted into the subsea pipeline due to sea water [4,5]. Also, high pressure and high temperature creates axial force on subsea pipeline [6]. Pipeline reacts due to hydraulic pressure and other pressures on the pipeline. This reaction is called buckling. In the buried pipeline, soil cover weight is less than the surrounding soil weight, so upheaval buckling is possible. Vertical movement is important in upheaval buckling of pipeline. The intensity of vertical reaction depends on the characteristics of the seabed [7-10]. So, seabed characteristic is one of the most important parameters in upheaval buckling. The importance of soil type has proven on upheaval buckling studies so that the soil type in this study are listed. In previous studies have been marked the type of seabed soil and theses study divided to two parts, clayey seabed [11,12] and sandy seabed [13,14] separately. Previous studies not discuss about detail of soil characteristics and its effect on upheaval buckling. ABAQUS standard code is the most commonly used software for numerical analysis of upheaval buckling. Previous studies are modeled seabed as rigid surface [15-17]. Analytical rigid surfaces are geometric surfaces with profiles that can be described with straight and curved line segments. An analytical rigid surface is associated with a rigid body reference node whose motion governs the motion of the surface. An analytical rigid surface does not contribute to the rigid body's mass or inertia properties analytical rigid surfaces are always single-sided with their orientation specified through their definition. Therefore, contact interaction is recognized only on the outer boundary of an analytical rigid surface. To model contact on both sides of a thin structure, use an analytical rigid surface that wraps around the boundary of the thin structure.

In this study, different seabed soils are considered and have been compared with each other. The main aim of this study is to evaluate the effect of soil types on upheaval buckling. In this study, the effect of temperature difference is evaluated for different types of soils. 10 difference temperature is considered for this evaluation. Upheaval buckling is modelled with ABAQUS standard code and seabed is modelled as 2d spring in 2 directions. The critical stress increases due to the soil cohesion increasing. The effect of difference temperature on the upheaval buckling increases due to increasing of angle friction. Soil cohesion is more effective parameter than soil angle friction of the soil.

2. FE model

The length of pipeline is considered 500 (m) for ABAQUS modeling. The two-dimensional beam elements were used to pipeline model. According to DNV-F-110 (2006) recommendation, mesh size assumes 0.5 (m). The pipeline is modelled as 2D beam with PIPE21 elements. Nonlinear spring with Spring1 element is used for seabed modeling.

Initial imperfection is a key parameter for upheaval buckling starting. The most common initial imperfection assumption used by the previous researchers, the sinusoidal profile imperfection is:

$$f(x) = {}^{W_0}/_{2}\left(1 + \cos\left({}^{2\pi x}/_{L_0}\right)\right). \quad -{}^{L_0}/_{2} \le x \le {}^{L_0}/_{2} \qquad (1)$$

Imperfection height and wavelength are defining imperfection parameters. Imperfection properties are shown in table 1.

Table 1. Imperfection properties

Characteristic	Value
Wave length(m)	60
Imperfection height(m)	0.15

Static analysis is used step in ABAQUS model. The basis of this analysis is nonlinear buckling analysis. There is difference temperature due to fluid flow through the pipeline in operation that is causing to axial force to pipeline. The amount of difference temperature is variable for this model.

The soil is modeled as spring in this model. Figure. 1 illustrates the general schematic of using axial, lateral and vertical springs for soil modeling of buried pipeline. The calculation of spring stiffness is based on standard code of American Lifelines Alliance [18].

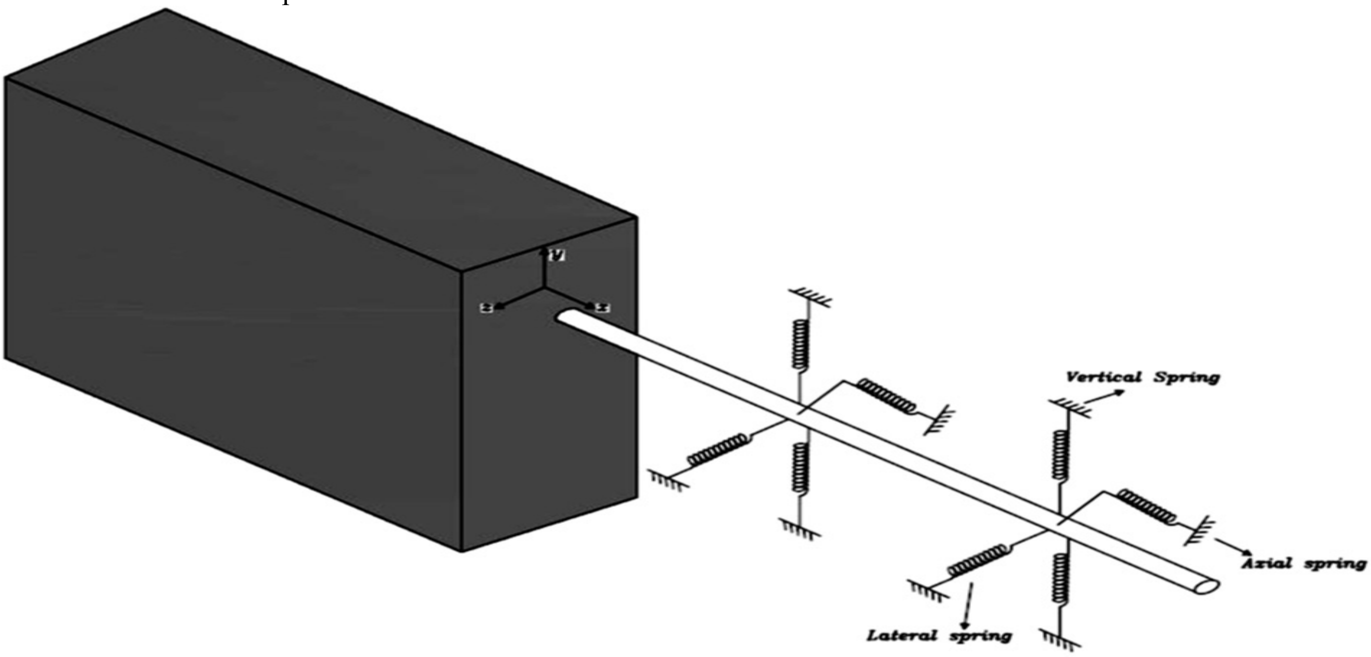

Figure 1. General schematic of using axial, lateral and vertical springs for soil modeling [18]

3. Methodology

This research is focused on the effect of soil specification on upheaval buckling. To achieve this aim, seabed is modeled with different types. Table 2 is shown the specification of used soils.

In the past 30 years, the researcher summarized models of buckling of the pipeline. These models are suitable for a certain condition.

The Terndrup-Pedersen's assumptions [20]:

· Pipeline a is linear beam;

· Seabed is rigid;

· Effect of the soil cover is fixed; this model is suitable for pipeline with the small vertical displacement;

· Pipeline is completely elastic;

· Pipeline and trench bottom may be imperfect;

· Initial imperfection is considered for seabed and pipeline.

The imperfection shape is defined by:

$$\omega_f = \delta_f \left(\frac{x}{L_0}\right)^3 (4 - \frac{3x}{L_0}) \quad (2)$$

Where

$$L_o = (\frac{72EI\delta_f}{q_f})^{\frac{1}{4}} \quad (3)$$

Where:

δ_f= Initial imperfection height

q_f= Pipe submerged weight

Figure.2, illustrates the imperfection shape of a pipeline with expressed assumptions. The pipeline loaded with a weight of per unit length. Also, it is assumed that the below area of pipe is not empty.

$$\omega_f = \delta_f \left(\frac{x}{L_0}\right)^3 (4 - \frac{3x}{L_0}) \quad (4)$$

Where

$$L_o = (\frac{72EI\delta_f}{q_f})^{\frac{1}{4}} \quad (5)$$

Where:

δ_f= Initial imperfection level

q_f= Pipe submerged weight

Figure.2, illustrates the deflection shape of an elastic pipeline with bending stiffness EI placed over a protruding object of height f and loaded with a weight of per unit length. Besides, it is assumed that the cavity below the propped pipe will be filled with soil, either through natural process or engineering backfill procedures.

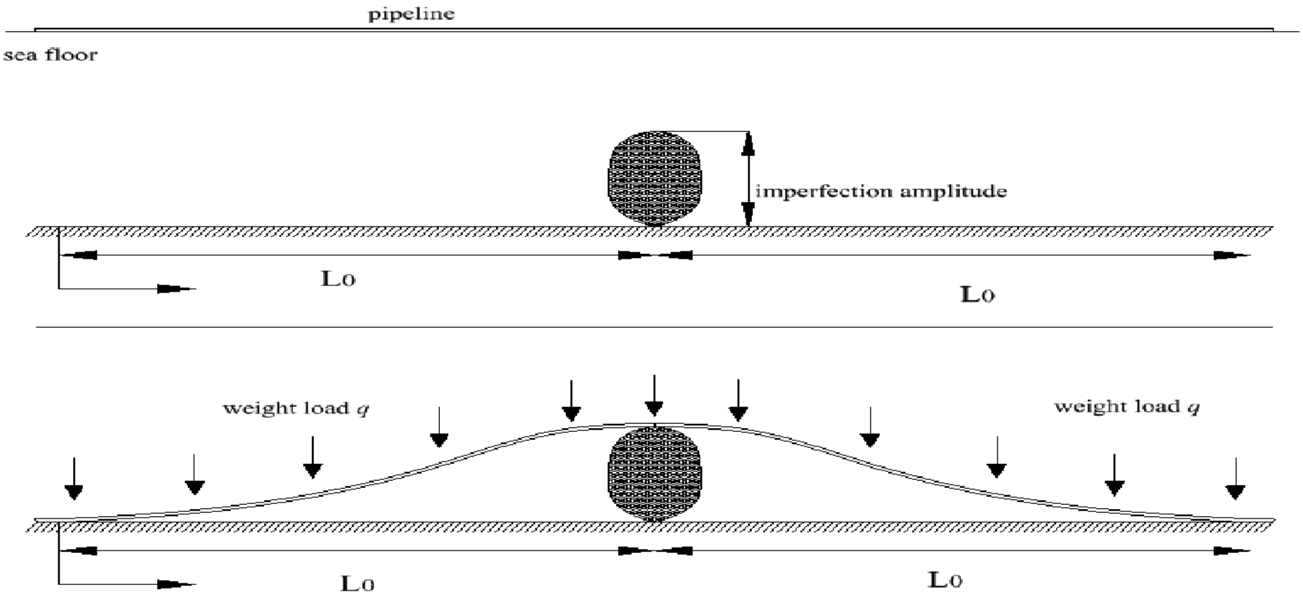

Figure 2. Pipeline position on initial imperfection [19]

Figure. 3, illustrate the uplift op pipeline with initial imperfection in the x-w coordinate system, as shown in, the uplift amount of pipeline with initial imperfection can be given as:

$$EI\frac{d^4}{dx^4}\left(\omega - \omega_p\right) + N\frac{d^2\omega}{dx^2} + q = 0 \quad (6)$$

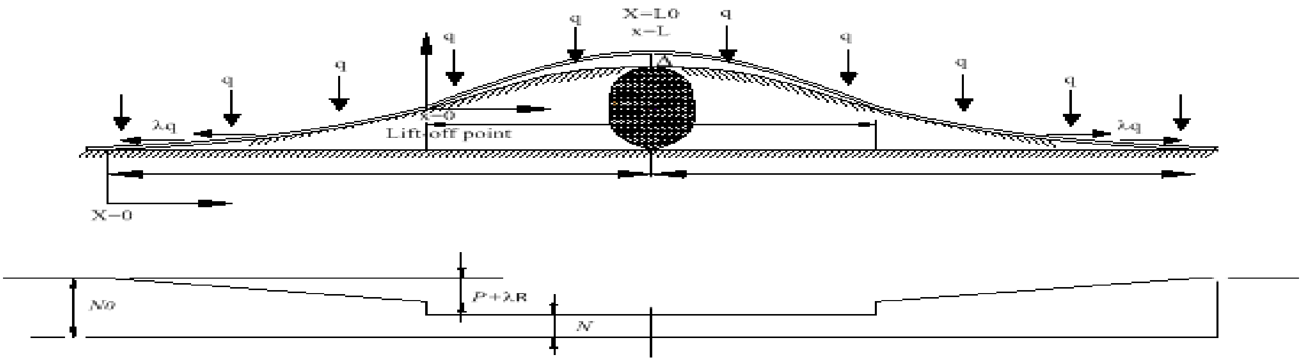

Figure 3. Upheaval buckling of pipeline with initial imperfection [19]

Table 2. Specification of different soil types

Parameters	Clay	Muddy Clay	Silty Clay	Reclaimed Sand (RS)	Drainage Coarse Sand (DCS)
$\rho_{sat}\ (KN/m^2)$	17.84	18.15	18.32	19.64	20.71
ϑ	0.30	0.35	0.30	0.28	0.25
$C\ (KPa)$	11	9	12	0	0
$\emptyset$ (°)	14	15	18	28.9	32

The general effective download can be given as:

$$q = q_{pipe} + q_s \qquad (7)$$

Where:

q_{pipe}= Pipe submerged weight

q_s= Uplift resistance of the cover material

Where:

$$q_s = \gamma_c \left(HD_o - \frac{\pi}{8} {D_o}^2 + H^2 tan\varphi_c \right) g \qquad (8)$$

$$q_{pipe} = m_0 g \qquad (9)$$

Where:

D_o= Overall outside diameter including coatings

c= Submerged weight of burial material per unit volume, 1023 kgm3 in this paper

g= Acceleration Due to Gravity

H= Minimum height of the cover soil measure between the pipe centerline and the seafloor

m0= Submerged mass per unit length of the pipeline
Then allowable temperature rise may be calculated with the equation.

$$N_o = \frac{\pi}{4} E\alpha_s \left({D_e}^2 - {D_i}^2 \right) \Delta T + \frac{\pi}{4} (1 - 2\vartheta)(p_i {D_i}^2 - p_o {D_e}^2) \qquad (10)$$

This modeling is focused on the effect of soil specification on upheaval buckling. To achieves this aim, seabed is modeled with different types. Table 2 is shown the specification of used soils.
Temperature plays important role in upheaval buckling. In this study, the effect of temperature difference is evaluated for different types of soil. 10 difference temperature is considered for this evaluation. 50 ℃ to 110 ℃ is the range of mentioned temperature.
In this study, the aim is the evaluation of the influence of soil characteristics on upheaval buckling. In this study, the soil is modeled as spring. The task of these springs is to react like soil against forces.

3.1. Results

Figure 2 shows the critical stress increase due to increasing of difference temperature. Figure2 describes this process for the different type of soils. According to soil characteristics which is shown in Table 1 and Figure. 2, the critical stress increases due to the soil cohesion increasing. According to the comparison between the curve of clay and muddy clay, soil cohesion is more effective parameter than soil angle friction of the soil.
Also, the slope of curves increases due to increasing of angle friction. In other words, the effect of difference temperature on the upheaval buckling increases due to increasing of angle friction.

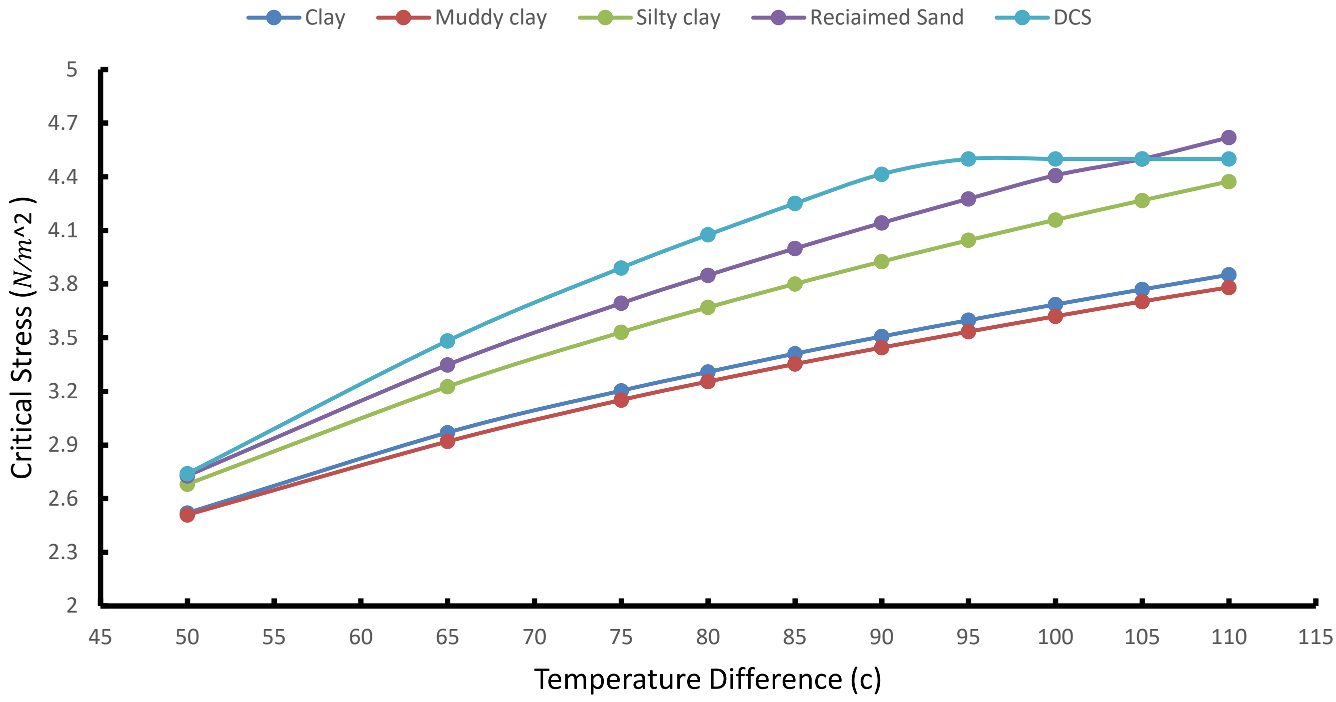

Figure. 2. The critical stress of upheaval buckling for different soils

Figure. 3. illustrates the maximum amplitude of upheaval buckling for different soils. As is shown in Figure. 3, the buckle amplitude increases due to increasing of soil cohesion in clay soils and the buckle amplitude increase due to increasing of friction angel in sand soils. According to distance between curves, the effect of temperature difference due to friction angel increasing in sandy soils is more than clayey soils. Also, the curve slope is constant for different soils.

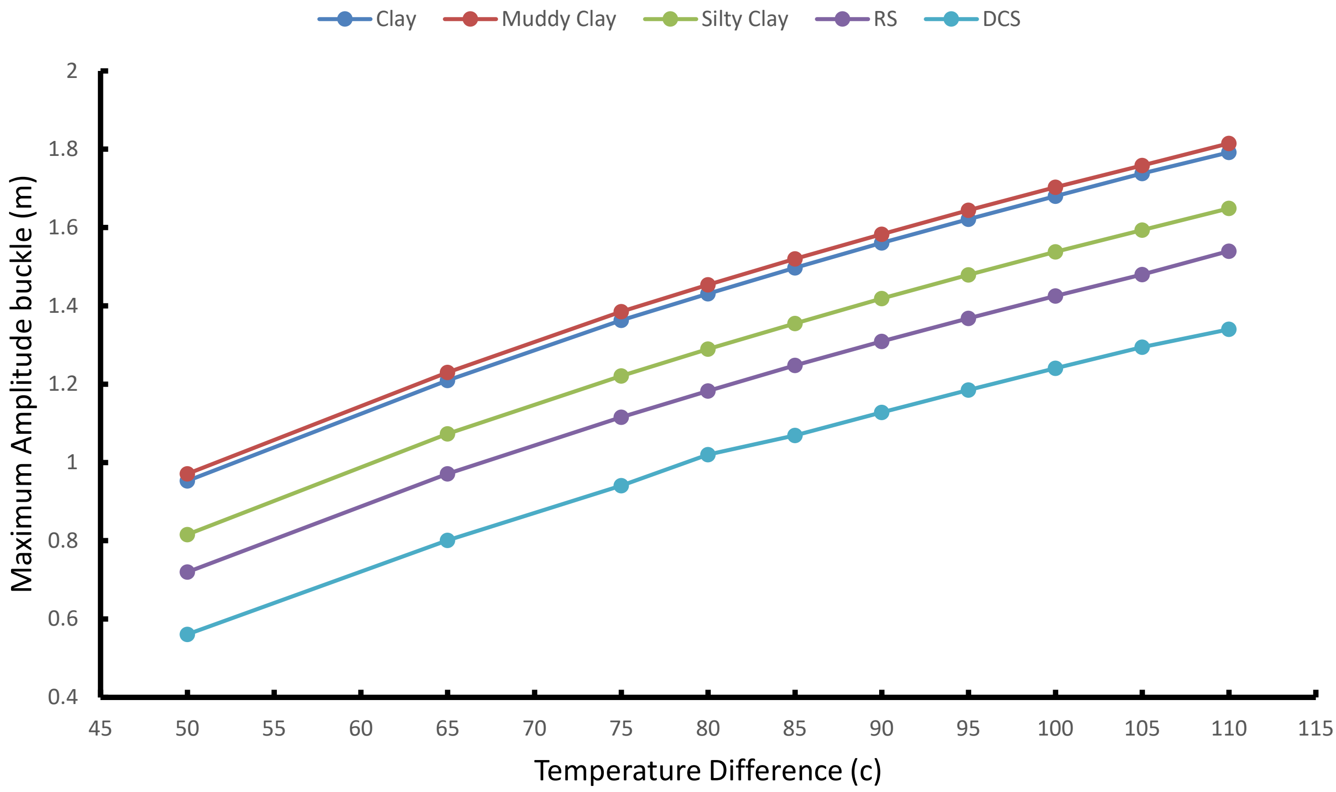

Figure 3. The maximum amplitude of upheaval buckling for different soils.

Figure 4 illustrates the critical temperature of upheaval buckling for different soils. As is shown in Figure 4, the slope of curves decreases due to increasing of friction angel of soil. In other words, the temperature difference is not effective on critical temperature in soils with high friction angel.

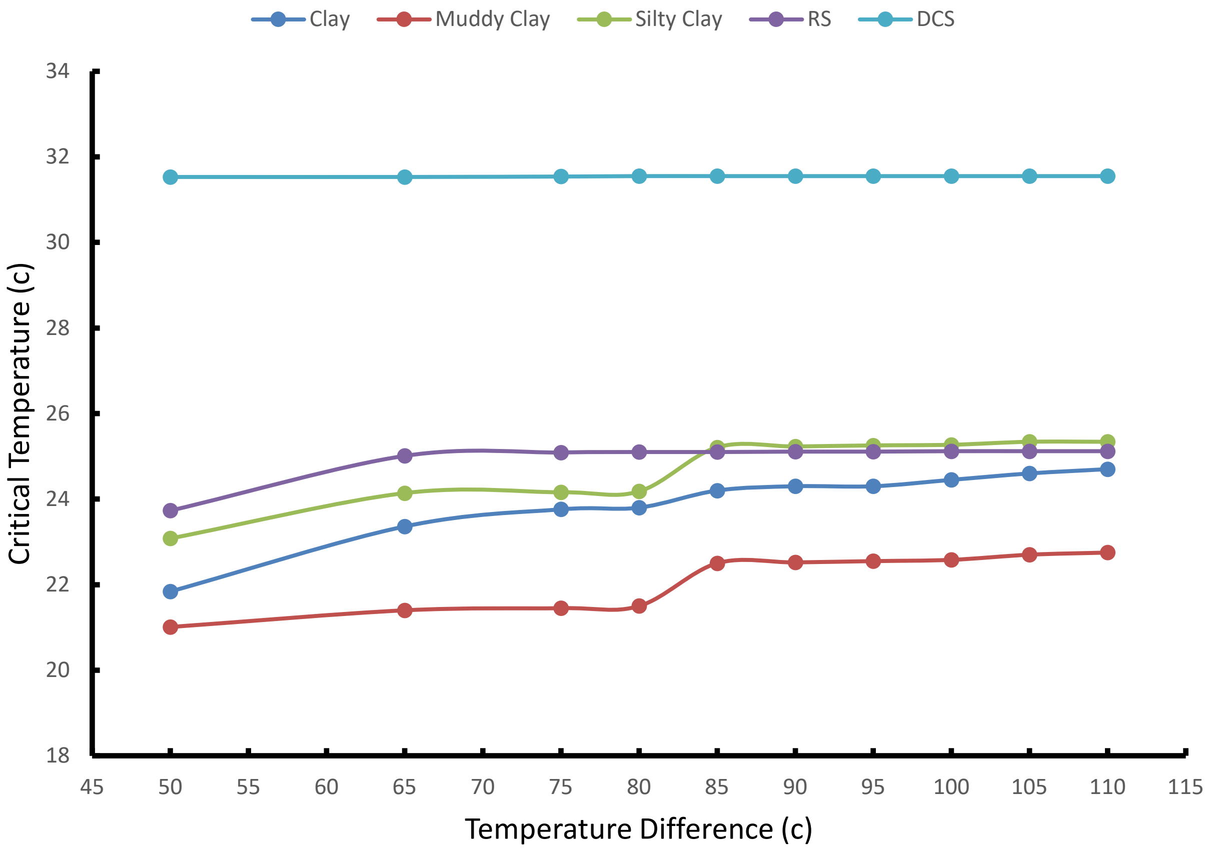

Figure 4. The critical temperature of upheaval buckling for different soils

5. Conclusions

- The critical stress increases due to the soil cohesion increasing
- Soil cohesion is more effective parameter than soil angle friction of the soil.
- The effect of difference temperature on the upheaval buckling increases due to increasing of angle friction.
- The buckle amplitude increases due to increasing of soil cohesion in clay soils and the buckle amplitude increase due to increasing of friction angel in sand soils
- The effect of temperature difference due to friction angel increasing in sandy soils is more than clayey soils
- The temperature difference is not effective on critical temperature in soils with high friction angel.

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