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# Mehanizacija pretovarnih radova kod deponija velikih zapremina

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*U radu je prikazano jedno rešenje mehanizacije pretovarnih radova kod velikih deponija. Ostvaruje se transportnim sredstvima uz funkcionalnu povezanost tih sredstava. Sa ovakvim rešenjem isključuje se transport otpada kamionima do samog mesta istovara (odlaganja) otpada, čime se znatno smanjuju troškovi transporta i sprečava mogućnost samozaglavljivanja teških kamiona u samoj deponiji.*

*Bunker za odlaganje otpada, transporter za punjenjekorpe sa otpadom, transport korpe sa otpadom preko čeličnih nosećih užadi do mesta istovara, čine strukturu fleksibilnog rešenja mehanizacije pretovarnih radova, koje posebno dolazi do izražaja kod deponija velikih zapremina.*

**Ključne reči: Mehanizacija, pretovar, deponija, transportna sredstva, noseća užad**

## 0. UVODNE NAPOMENE

Deponovanje komunalnog otpada se vrlo često ostvaruje na neuređenim i nepripremljenim terenima, što negativno utiče na stanovništvo kao i na zagađenje voda, zemljišta i vazduha. Treba napomenuti da prikupljanje, transport i odlaganje otpada vrše komunalna preduzeća sa po pravilu, zastarelom mehanizacijom (Sl.1), najčešće bez selektivnog razvrstavanja (bez reciklaže).

*Sl. 1: Prikupljanje, transport i odlaganje otpada*

Da bi se navedene negativnosti odstranile, potrebno je sprovesti sledeće aktivnosti:

- pre svakog deponovanja otpada obavezno izvršiti razvrstavanje (sortiranje),
- projektom sanitarnih deponija komunalnog otpada obuhvatiti više opština (formiranje velikih deponija), pri čemu treba koristiti dobra rešenja i iskustva zemalja Zapadne Evrope,
- zaštititi izvorišta voda, rečne tokove, zemljište i vazduh,
- NUS (sporedne) proizvoda i deponijski gas usmeriti ka pretvaranju u električnu energiju,
- sprovoditi stalnu edukaciju stanovništva o značaju i ulozi deponija.

Pojava regionalnih sanitarnih deponija, kao opravdana rešenja, sve više dolaze do izražaja u poređenju sa gradskim deponijama jer dugoročno rešavaju problem odlaganja otpada. Jasno je da projekat regionalne deponije predstavlja složen infra-strukturni objekat koji zahteva rešavanje uticajnih parametara, kao što su:

- lokacija deponija,
- vrsta i obim otpadnog materijala,
- karakteristike otpadnog materijala,
- dostupnost površine za planiranje deponije,
- geotehnički i urbanistički preduslovi za oblikovanje profila deponije (osobine i karakteristike zemljišta ispod deponije, izolacija propustljivosti sadržaja otpada u zemljište ispod deponije, odvođenje deponijskog gasa, zatvaranje deponije,
- kasnije korišćenje površine na mestu izgrađene deponije,
- zakonske regulative i prateći propisi.

Lokacija deponije treba da obezbedi potpunu sanitarnu-epidemiološku sigurnost za stanovništvo i radnike, kao i zaštitu od zagađenja zemljišta,voda i vazduha. Zato se za lokacije deponija najčešće koriste:

- uvale zaklonjene bočnim strmim terenima,
- dubodoline koje su nastale prirodnim putem,
- dubodoline koje su nastale vađenjem ruda ili građevinskih materijala, pri čemu pri završetku formiranja deponija treba težiti uklapanju novonastale površine sa okolnim terenom (Sl.2).

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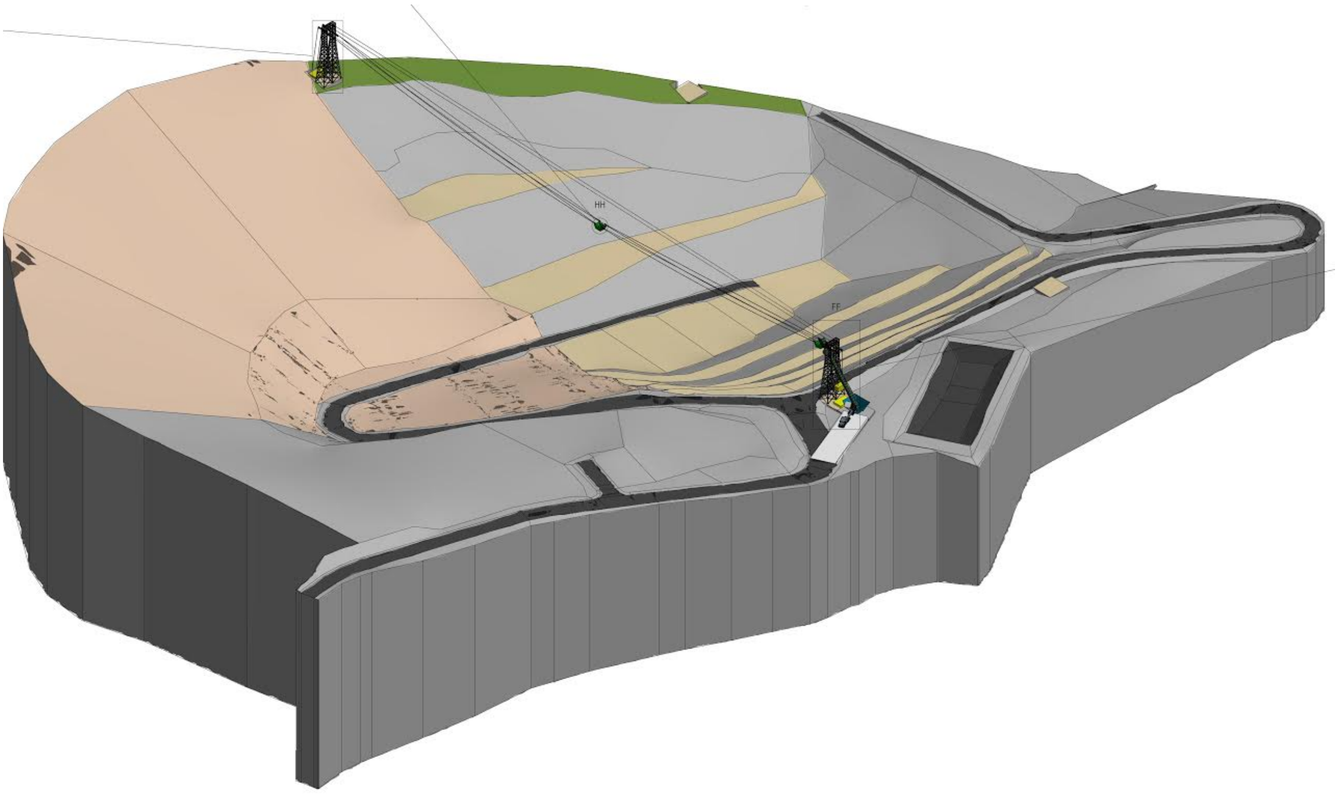
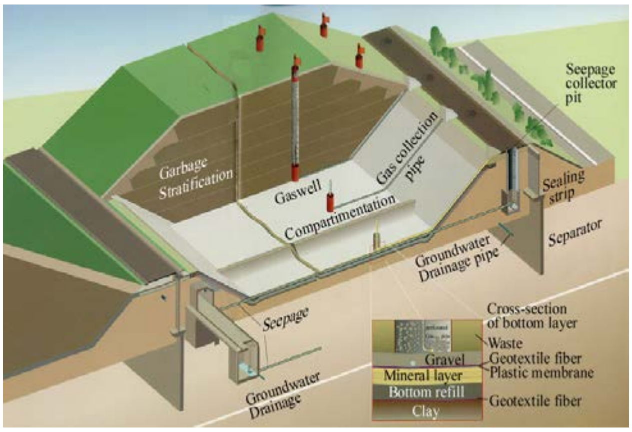


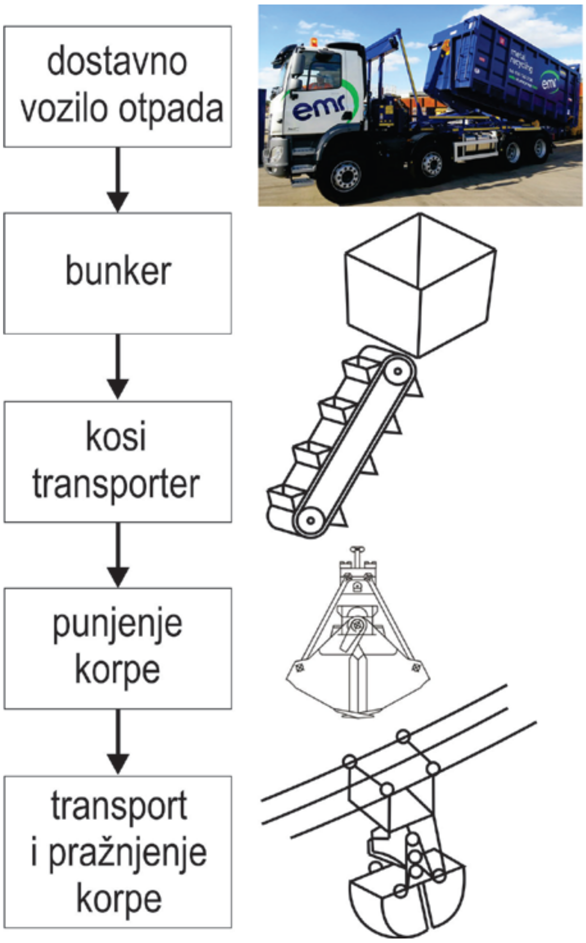
*Sl. 2: Novoformirana regionalna deponija*

## 1. UTOVARNO - ISTOVARNI RADOVI NA VELIKIM DEPONIJAMA SREDSTVIMA TRANSPORTNE MEHANIZACIJE

Kao što je poznato, transport otpadnog materijala u gradske deponije se najčešće ostvaruje kamionima za prevoz otpada. Otpad se istresa iz kamiona, zatim razastire buldozerima sa utovarnom lopatom uz sabijanje kompaktorima i na kraju se vrši prekrivanje slojem inertnog materijala. Kada je reč o velikim (regionalnim) deponijama (Sl.3) ovakav način odlaganja otpada je neprimenljiv pre svega zbog dovoženja velikih količina otpadnog materijala. Često je otežano i vrlo nemoguće vršiti istovar otpadnog materijala sa kamiona u samoj zoni deponije, jer sam teren ne pruža uslove za odgovarajuću prohodnost, što direktno utiče na smanjenje kapaciteta transporta uz povećanje troškova.



*Sl. 3: Regionalna deponija*

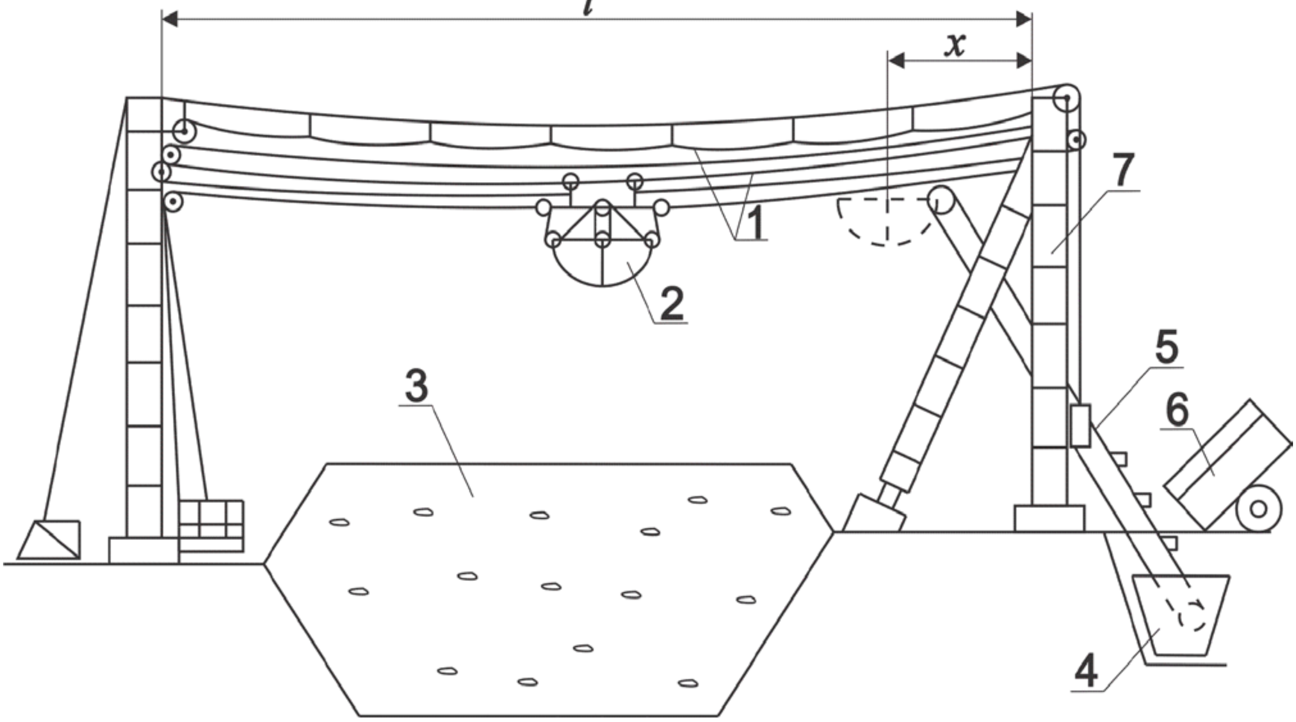


*Sl. 4: Funkcionalna povezanost sredstava transportne mehanizacije*

Istovarno-utovarni radovi sredstvima transportne mehanizacije se pojavljuju kao rešenje koje može da ispuni zahteve efikasnog i ekonomičnog odlaganja velikih količina otpada.

Funkcionalna povezanost sredstava transportne mehanizacije šematski je prikazana na Sl.4.

Šema transportne mahnizacije za istovar, transport i odlaganje otpada, prikazana je na Sl.5.



*Sl. 5: Šema transportne mahnizacije za istovar, transport i odlaganje otpada*

Pozicije nprikazane na Sl.5 su:

1) Čelična užad,
2) Korpa,
3) Deponija,
4) Bunker,
5) Kosi transporter,
6) Transportno vozilo,
7) Stub.

Iz bunkera (4) sa otpadom koji se istresa iz dovoznih (transportnih) kamiona (6) pužnim ili drugim transporterima (5) se puni korpa (2) na rastojanju "x" od stuba (7), koja se zatim premešta duž užadi (1) do mesta istovara.

Osnovni parametri koji karakterišu ovo konceptno rešenje su:

- dužina transportnog puta korpe: $50 \div 500(m)$

- nosivost korpe: $1{,}0 \div 15(t)$

- visina stubova: $5{,}0 \div 50(m)$

- brzina dizanja korpe: $1{,}0 \div 6{,}3(m/s)$

- brzina premeštanja korpe: $0{,}1 \div 0{,}3(m/s)$

- prosečno vreme trajanja transportnog ciklusa korpe (zavisi od širine deponije): $120 \div 180(s)$

- prosečno vreme punjenja korpe (zavisi od visine stubova): $90 \div 120(\mathrm{s})$

## 2. OSNOVE PRORAČUNA PARAMETARA SISTEMA UŽADI - RAČUNSKI PRIMER

Za proračun parametara sistema užadi kabl dizalice sa korpom (Sl.5) mogu se koristiti osnove teorije proračuna [1, 4], pri čemu se zadaju projektni parametri:

$l = 200\,m$ - raspon između nosećih stubova,

$\beta = 0{,}035(rad)$ - ugao denivelacije vrhova stubova,

$m_t = 5(t)$ - masa tereta koji se transportuje i spušta do mesta istovara ( $P_t = 49{,}05\,kN$ ),

$m_k = 0{,}7(t)$ - masa noseće korpe ( $P_k = 6{,}86\,kN$ ),

$Q = 49{,}05 + 6{,}86 \approx 56\,kN$ - ukupno pokretno opterećenje,

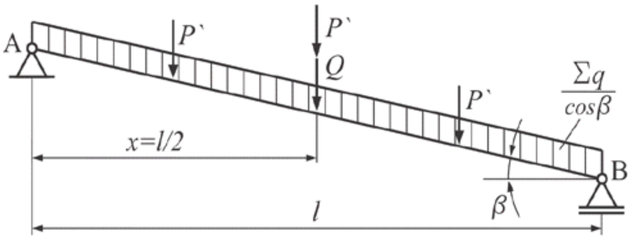
$m_d = 0{,}05(t)$ - masa držača užadi (tri držača) ( $P' = 0{,}49\,kN$ ),

$E_u = 1{,}6 \cdot 10^8\,(kPa)$ - modul elastičnosti čeličnih užadi,

$A_u = 0{,}003232(m^2)$ - površina metalnog preseka užeta,

$\sigma_v = 1372\,MPa$ - zatezna čvrstoća žica užeta

Za određivanje visine deponije, potrebno je izvršiti određivanje ugiba na sredini raspona ( $x = \frac{l}{2}$ ) (Sl. 6).



*Sl. 6: Određivanje ugiba na sredini raspona*

Ugib užadi pri položaju korpe sa teretom, na rastojanju "x" definisan je formulom [4]:

$$f_x=\left(Q+n\cdot P'+0{,}5\cdot l\cdot\Sigma q/\cos\beta\right)\cdot\left(l-x\right)\cdot x/l\cdot\Sigma H_x \qquad (1.1)$$

Kako se najveći ugib javlja pri položaju korpe sa teretom na rastojanju $x=\frac{l}{2}$, to je

$$f_{(l/2)}=\left(Q+n\cdot P'+0{,}5\cdot l\cdot\Sigma q/\cos\beta\right)\cdot l/4\cdot\Sigma H_{l/2} \qquad (1.1,a)$$

Za određivanje ugiba na sredini može se koristiti empirijska formula

$$f_{(l/2)}=\left(40+0{,}05\cdot l\right)\cdot l/\sigma_v=\left(40+0{,}05\cdot 200\right)\cdot 200/1372$$

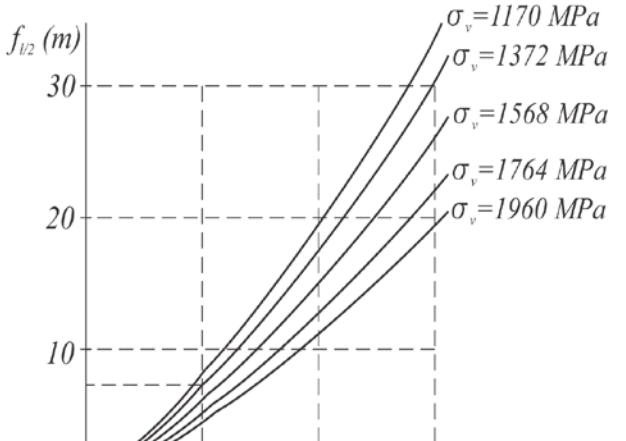
$$f_{(l/2)}=7{,}3m$$

ili preko dijagrama (Sl.7), pri čemu je dozvoljeni ugib na sredini:

$$f_{(l/2)}^{d}=\left(0{,}03\div 0{,}08\right)\cdot l=\left(0{,}03\div 0{,}08\right)\cdot 200=\left(6\div 16\right)m$$

Ravnomerno raspoređeno opterećenje $\Sigma q$ se određuje iz zavisnosti

$$\Sigma q=\left(Q+n\cdot P'\right)\cdot C_q/\left[528+\left(0{,}66-0{,}5\cdot C_q\right)\cdot l\right] \qquad (1.2)$$



*Sl. 7: Zbirne zatezne sile u osloncima A i B*

gde je $C_q=1{,}13$ - koeficijent kabl dizalice sa grabilicom

Posle zamene vrednosti u (1.2) dobija se

$$\Sigma q=\left(56+3\cdot 0{,}49\right)\cdot 1{,}13/\left[528+\left(0{,}66-0{,}5\cdot 1{,}13\right)\cdot 200\right]$$

$$\Sigma q=0{,}12\frac{kN}{m}$$

Težina užadi $G$ određuje se iz izraza

$$G=l\cdot\Sigma q/\cos\beta=200\cdot 0{,}12/0{,}9994=24kN$$

Pri položaju korpe sa teretom na sredini horizontalna zatezna sila u sistemu užadi iznosi

$$\Sigma H_{(l/2)}=\left(Q+n\cdot P'+0{,}5\cdot l\cdot\Sigma q/\cos\beta\right)\cdot l/4\cdot f_{(l/2)} \qquad (1.3)$$

Posle zamene

$$\Sigma H_{(l/2)}=\left(56+3\cdot 0{,}49+0{,}5\cdot 200\cdot 0{,}12/0{,}9994\right)\cdot 200/4\cdot 7{,}3$$

$$\Sigma H_{(l/2)}=476kN$$

Vertikalna zatezna sila u osloncima A i B se određuje iz formule (1.4) i (1.5)

$$\Sigma V_{Ax}=Q\cdot\frac{l-x}{l}+n\cdot P'\left(1{,}5-\frac{x}{l}\right)+\left(\frac{l}{2\cos\beta}\right)\Sigma q\pm \pm\Sigma H_x tg\beta \qquad (1.4)$$

$$\Sigma V_{Bx}=Q\cdot\frac{x}{l}+n\cdot P'\left(0{,}5-\frac{x}{l}\right)+\left(\frac{l}{2\cos\beta}\right)\Sigma q\mp \mp\Sigma H_x tg\beta \qquad (1.5)$$

Za $x=\frac{l}{2}$, sledi:

$$\Sigma V_{Ax}=56\cdot\frac{200-100}{200}+3\cdot 0{,}49\left(1{,}5-\frac{100}{200}\right)+ +\frac{200}{2\cdot 0{,}9994}\cdot 0{,}12+476\cdot 0{,}035=58kN$$

$$\Sigma V_{Bx}=56\cdot\frac{100}{200}+3\cdot 0{,}49\left(0{,}5-\frac{100}{200}\right)+\frac{200}{2\cdot 0{,}9994}\cdot 0{,}12- -476\cdot 0{,}035=25kN$$

Zbirne zatezne sile u osloncima A i B (Sl.6) iznose:

- oslonac A:

$$\Sigma T_{A(l/2)}=\sqrt{\left(\Sigma H_{(l/2)}\right)^2+\left(\Sigma V_{A(l/2)}\right)^2}= =\sqrt{476^2+58^2}=479kN \qquad (1.6)$$

- oslonac B:

$$\Sigma T_{B(l/2)}=\sqrt{\left(\Sigma H_{(l/2)}\right)^2+\left(\Sigma V_{B(l/2)}\right)^2}= =\sqrt{476^2+25^2}=477kN \qquad (1.7)$$

Uglovi nagiba užadi u osloncima A i B određuju se iz izraza:

$$\left.\begin{aligned}\alpha_{A(l/2)}&=arctg\frac{\Sigma V_{A(l/2)}}{\Sigma H_{(l/2)}}=\frac{58}{476}=0{,}12rad\\ \alpha_{B(l/2)}&=arctg\frac{\Sigma V_{B(l/2)}}{\Sigma H_{(l/2)}}=\frac{25}{476}=0{,}05rad\end{aligned}\right\} \qquad (1.8)$$

Punjenje korpe se ostvaruje na rastojanju $x=20m$.

Određivanje horizontalnih komponenti užadi se određuje iz jednačine (1.9)

$$\left(\Sigma H_x\right)^3+\left(\Sigma H_x\right)^2\left\{E_uA_u\left[\frac{\cos^5\beta}{2l\left(\Sigma H_{(l/2)}\right)^2}\int_0^l\left(\Sigma Q_{b(l/2)}\right)^2dx\pm\right.\right. \qquad (1.9)$$

$$\left.\left.\pm\varepsilon\Delta t\cos\beta\right]-\Sigma H_{(l/2)}-E_uA_u\frac{\cos^5\beta}{2l}\int_0^l\left(\Sigma Q_{b(l/2)}\right)^2dx=0\right.$$

Može se uzeti da je $\Delta t = 0$ .
Kako je

$$\int_0^l \left(\Sigma Q_b\right)^2 dx = \left[ Q\left(Q + 2nP' + G\right) + nP'\left(nP' + 2\frac{G}{3}\right)\right] \cdot \cdot \left(l - x\right) \cdot \frac{x}{l} + \left(nP' + G\right)^2 \cdot \frac{l}{12} \qquad (1.10)$$

Posle zamene sledi:

Takođe iz izraza (1.11)

$$\int_0^l \left(\Sigma Q_{b(l/2)}\right)^2 dx = = \left[ Q\left(Q + 2nP' + G\right)/4 + \left(2nP' + G\right)^2/12 \right] \cdot l \qquad (1.11)$$

sledi:

$$\int_0^l \left(\Sigma Q_{b(l/2)}\right)^2 dx = \left[0,25 \cdot \left(0,25 + 2 \cdot 3 \cdot 0,49 + 24\right)/4 + + \left(2 \cdot 3 \cdot 0,49 + 24\right)^2/12\right] \cdot 200 = 244500\, kN^2 m$$

Posle zamene (1.10) i (1.11) u (1.9) dobija se jednačina:

$$\left(\Sigma H_x\right)^3 + \left(\Sigma H_x\right)^2 \left(1,6 \cdot 10^8 \cdot \frac{0,003232}{2 \cdot 200 \cdot 476^2} - 244500 \cdot 0,9994^5 - -476\right) - \frac{1,6 \cdot 10^8 \cdot 0,003232 \cdot 0,9994}{2 \cdot 200} \cdot 83130 = 0$$

Posle sređivanja, dobija se krajnji oblik jednačine (1.10):

$$\left(\Sigma H_x\right)^3 + 915\left(\Sigma H_x\right)^2 - 107470464 = 0 \text{ ,}$$

čije je rešenje:

$$\Sigma H_x = 298\, kN$$

Vertikalna komponenta sile zatezanja užadi u osloncu A, pri $x = 20\, m$ , iznosi:

$$\Sigma V_{A(20)} = 56 \cdot \left(200 - 20\right)/200 + 3 \cdot 0,49 \cdot \left(1,5 - 20/200\right) + + \left(0,5 \cdot 200 \cdot 0,12\right)/0,9994 + 298 \cdot 0,035 = 75\, kN$$

Vertikalna komponenta sile zatezanja užadi u osloncu B, pri $x = 180\, m$ , iznosi:

$$\Sigma V_{B(180)} = 56 \cdot 180/200 + 3 \cdot 0,49 \cdot \left(0,5 + 180/200\right) + + \left(0,5 \cdot 200 \cdot 0,12\right)/0,9994 - 298 \cdot 0,035 = 54\, kN$$

Zbirne zatezne sile u osloncima A i B su:

$$\Sigma T_{A(20)} = \sqrt{298^2 + 75^2} = 307\, kN$$

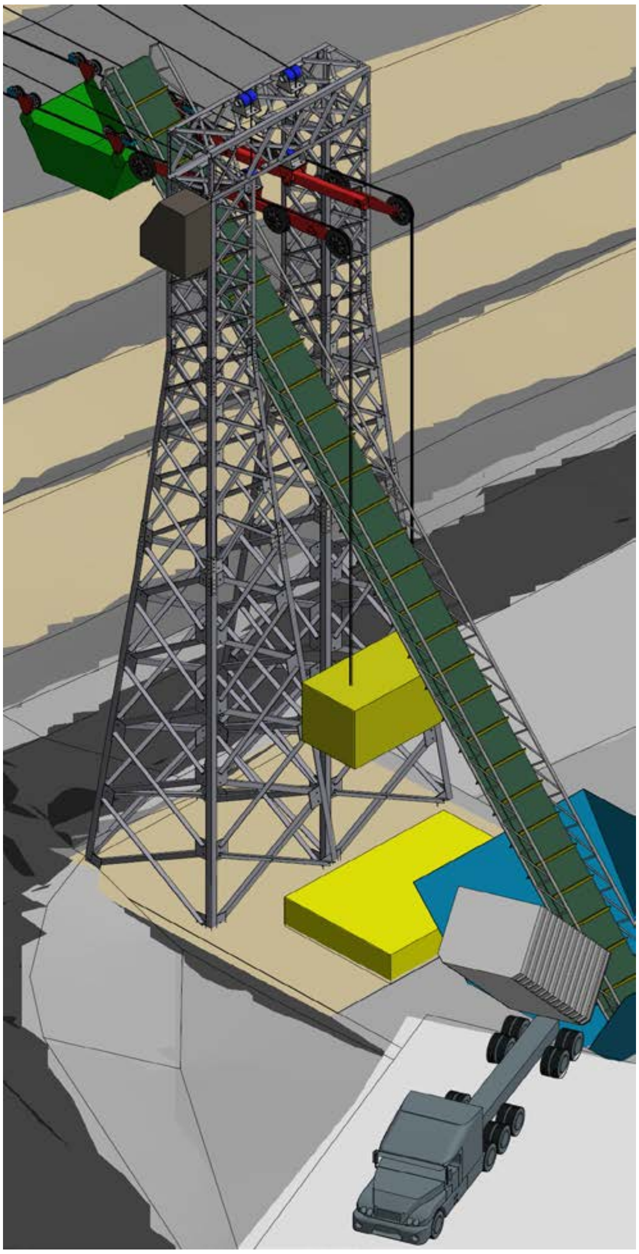
$$\Sigma T_{B(180)} = \sqrt{298^2 + 54^2} = 303\, kN$$

Nagibi užadi iznose:

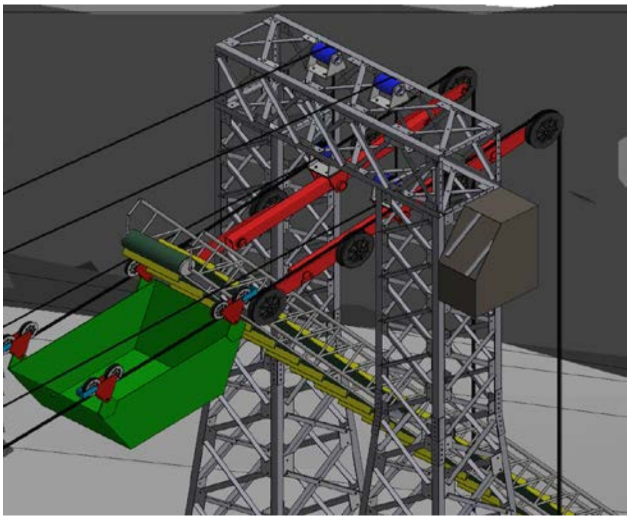
$$\alpha_{A(20)} = arctg \frac{75}{298} = 0,25\, rad$$

$$\alpha_{B(180)} = arctg \frac{54}{298} = 0,18\, rad$$

Jedan od stubova i položaj korpe pri punjenju prikazani su na slikama 7 i 8.



*Sl. 7: Stub i položaj korpe pri punjenju*



*Sl. 8: Položaj korpe pri punjenju*

## 3. ZAKLJUČAK

Primena sredstava transportne mehanizacije se pojavljuje kao optimalni koncept pri utovarno-istovarnim radovima na velikim deponijama jer se:

- smanjuju troškovi transporta u predelu same deponije,
- sprečavaju mogućnosti zapadanja transportnih vozila sa otpadom u deponijskom prostoru,
- može se ostvariti veliki kapacitet odlaganja otpada,
- gabariti deponije se ne pojavljuju kao ograničavajući parametric (dužina x širina) pri utovarno istovarnim radovima,
- pri zatvaranju deponije sredstva transportne mehanizacije se mogu premestiti na novu lokaciju.

## ZAHVALNOST

Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Srbije na podršci za realizaciju projekta TR 35008.

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# Mechanization of reloading works at the landfills of large volumes

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The paper presents one solution for mechanization of municipal waste handling at the large landfills. Means of transportation are functionally integrated into transportation chain. This solution excludes the usage of trucks for waste disposal at the landfill area, which significantly reduces the costs of waste disposal and excludes the possibility of trucks to get stuck in the landfill.

The entrance storage bunker, the transporter for charging the bucket and the steel rope system for the transportation of loaded and empty bucket to the discharge point are components of the flexible solution for the mechanization of municipal waste handling, which is especially convenient for the large landfills.

**Keywords: Mechanization, waste handling, landfill, transport mechanization, steel ropes, example.**

## 0. INTRODUCTORY REMARKS

Disposal of municipal waste is often done at unregulated and unprepared grounds, which has a negative effect on the population as well as on water, land and air pollution. It should be noted that collection, transportation and disposal of waste are done by municipal companies which, as a rule, use old mechanization and generally do not make selective classification of waste (there is no waste recycling) (Fig.1).

*Fig. 1 Transportation and disposal of waste*

To eliminate above stated negative effects it is necessary to perform the following activities:

- classification (sorting) of waste must be done before waste disposal,
- several municipalities should be involved in the project of sanitary landfills (formation of large landfills), with the application of good solutions and experience of Western European countries,
- protection of water springs, river flows, soil and air,
- by-products (landfill gas) should be converted into electrical energy,
- population should be regularly educated on the importance and role of landfills.

Regional sanitary landfills, as a justifiable solution, are becoming prominent in comparison to urban landfills, because they solve the problem of waste disposal over the long term. It is clear that the project of regional landfill is a complex infrastructural facility which requires many influential parameters to be solved:

- location of the landfill,
- type and amount of waste materials,
- properties of waste materials,
- availability of the area meant for landfill planning,
- geotechnical and urban preconditions which are needed to make the landfill profile (characteristics and properties of the land beneath the landfill, isolation of permeability of waste into the land beneath the landfill, use of landfill gas, landfill closure),
- later use of the area where the landfill is built,
- legal regulations and accompanying rules.

The landfill location should provide total sanitary and epidemiological safety of the local population and workers, as well as the protection against land, water and air pollution. Thus, the following locations are usually used to make landfills:

- coves sheltered by steep sides of cliffs,
- natural deep valleys,
- deep valleys made by extraction of ore or building materials, where the newly formed area should fit into the surrounding terrain after landfill is made (Fig.2).

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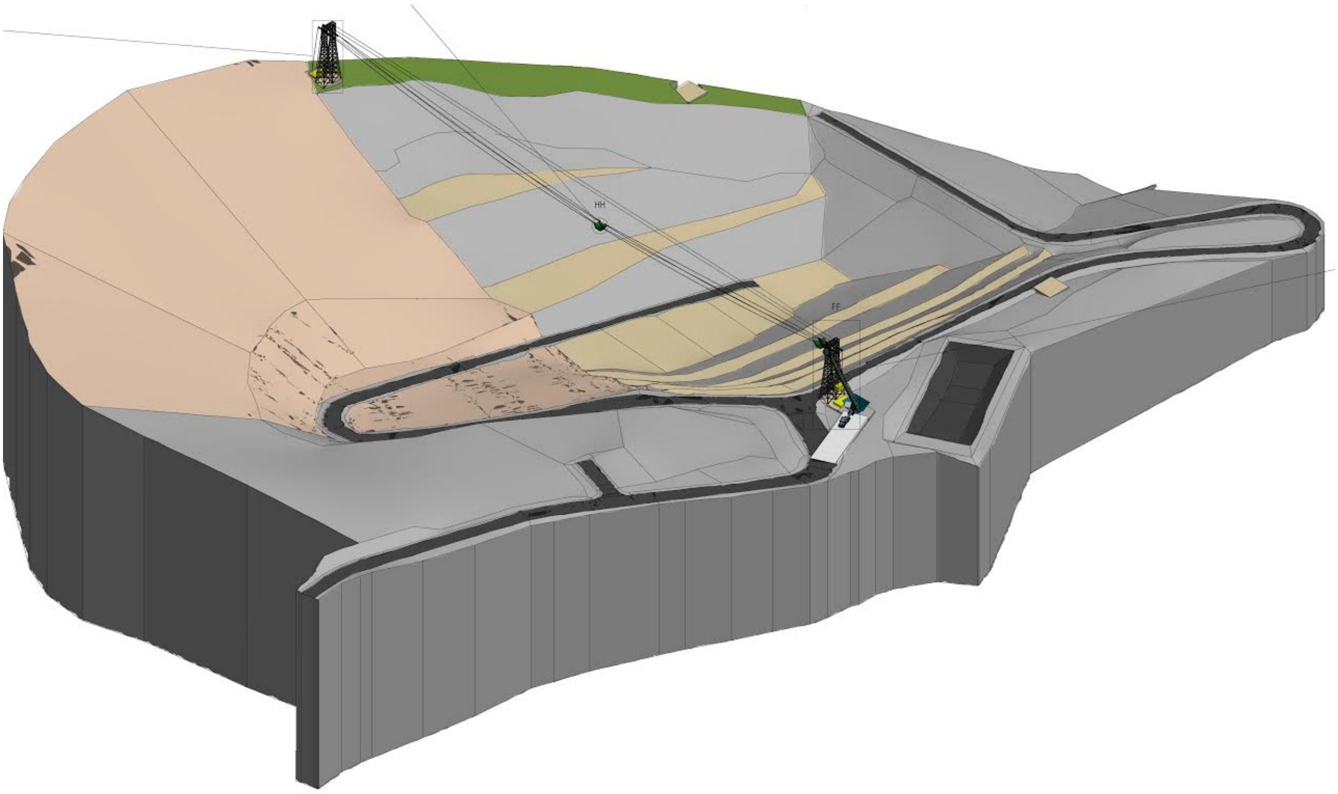

*Fig. 2 The newly formed regional sanitary landfill*

## 1. LOADING - UNLOADING WORKS ON LARGE LANDFILLS BY MEANS OF TRANSPORT MECHANIZATION

As stated above, transportation of waste materials to urban landfills is mostly done by special trucks for waste transport. Waste is unloaded from the truck, and then spread by bulldozers having loading shovel and compressed by compactors. Finally, it is covered by a layer of inert materials.

When it comes to large (regional) landfills (Fig.3) this method of waste disposal is inapplicable primarily due to the shipment of large quantities of waste material. It is hard and sometimes almost impossible to unload waste materials from trucks at the very area of the landfill, because the terrain itself does not provide conditions for adequate mobility, which directly influences the decrease of transportation capacity and increase of costs.

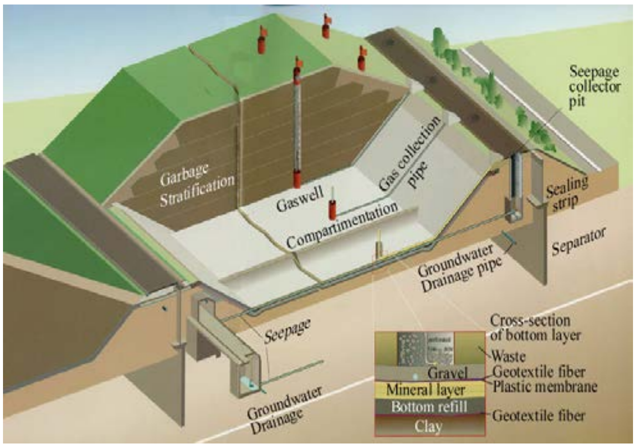

*Fig. 3 Regional sanitary landfill*

The concept of loading and unloading work by means of transport mechanization is a solution which can meet the requirements of efficient and economical disposal of large quantities of waste.

Functional connection between the means of transport mechanization is presented in Fig..4.

Scheme of transport mechanization for unloading, transport and waste disposal, is shown on Fig.5.

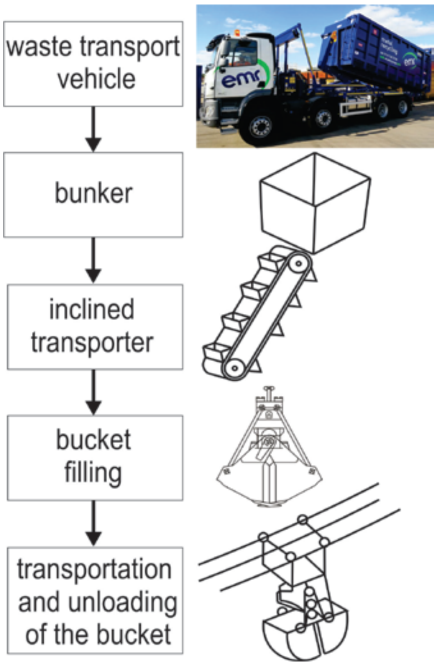

*Fig. 4 Functional connection between the means of transport mechanization*

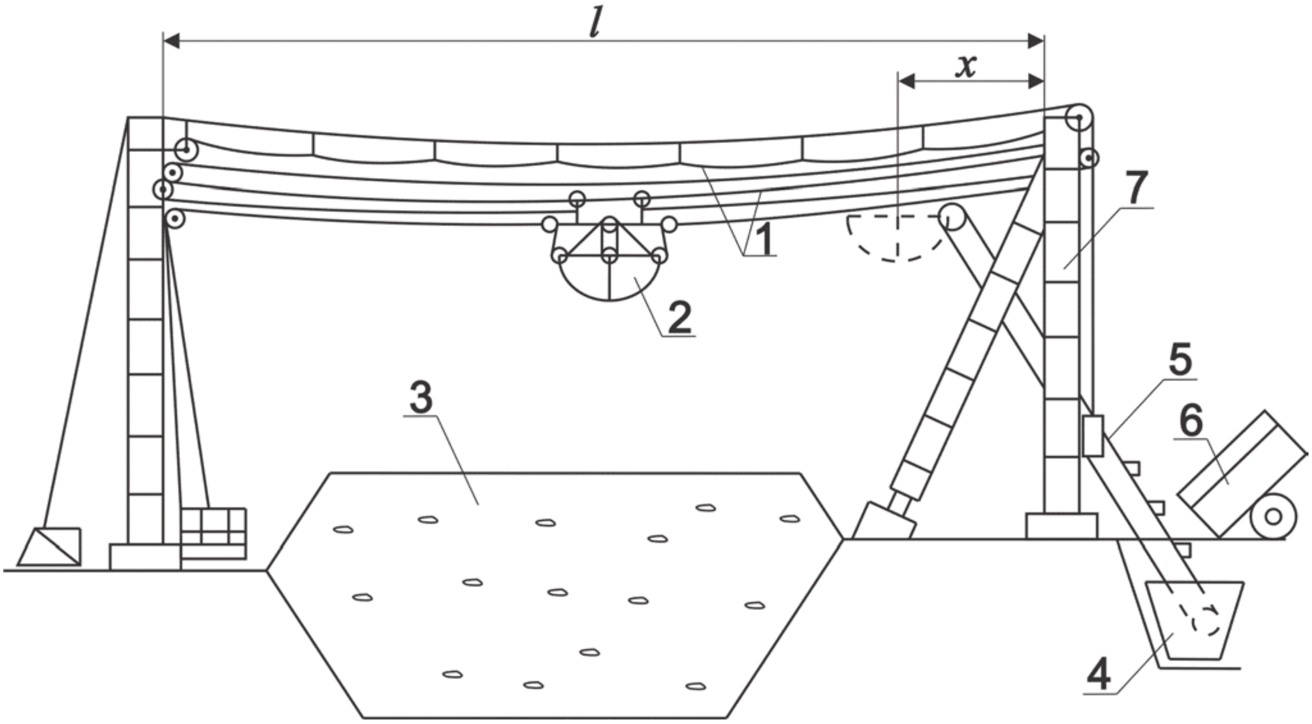

*Fig. 5 Scheme of transport mechanization for unloading, transport and waste disposal*

Positions shown on Fig.5 are:

1) Steel ropes,
2) Bucket,
3) Landfill,
4) Bunker,
5) Inclined transporter,
6) Transport vehicle,
7) Column.

From storage bunker (4) containing waste being unloaded from trucks (6), worm transporters or some other types of transporters (5) (such as scraper transporter) fill the bucket (2) on distance "x" from column (7) which is moved along the steel ropes to the loading position.

Basic parameters of the presented concept are:

- length of transporting path of the bucket: $50 \div 500(m)$

- bucket capacity: $1,0 \div 15(t)$

- column height: $5,0 \div 50(m)$

- speed of bucket lifting: $1,0 \div 6,3(m/s)$

- speed of bucket movement: $0,1 \div 0,3(m/s)$

- average time of bucket transportation cycle (depending on landfill width): $120 \div 180(s)$

- average time of bucket loading (depending on column height): $90 \div 120(\mathrm{s})$

## 2. ESSENTIALS OF CALCULATING THE PARAMETERS OF ROPE SYSTEM – CALCULATING EXAMPLE

To calculate the parameters of the rope system at the cable crane with the bucket (Fig. 5) the essentials of calculation theory can be used [1, 4] with the following parameters defined by the project:

$l = 200\,m$ - distance between supporting columns,

$\beta = 0,035(rad)$ - angle defining the difference between column tops,

$m_t = 5(t)$ - mass of load transported to and lowered at unloading place ( $P_t = 49,05\,kN$ ),

$m_k = 0,7(t)$ - mass of bucket's self weight ( $P_k = 6,86\,kN$ ),

$Q = 49,05 + 6,86 \approx 56kN$ - total moving load,

$m_d = 0,05(t)$ - mass of rope holders (three holders) ( $P' = 0,49\,kN$ ),

$E_u = 1,6 \cdot 10^8\,(kPa)$ - elastic modulus of steel ropes,

$A_u = 0,003232(m^2)$ - area of metallic section of the rope,

$\sigma_v = 1372\,MPa$ - tensile strength of rope wires.

Determination of deflection at the middle of distance ( $x = \dfrac{l}{2}$ ) (Fig. 6).

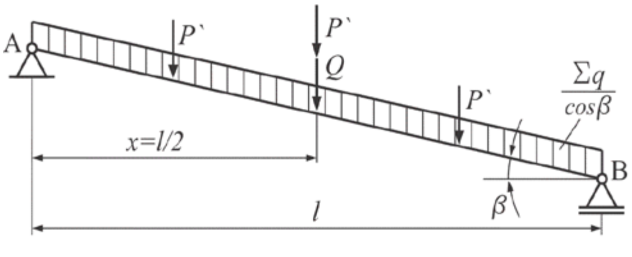

*Fig. 6 Determination of deflection*

Deflection of ropes when the bucket is loaded at the distance "x" is defined by the formula:

$$f_x = \left(Q + n \cdot P' + 0,5 \cdot l \cdot \Sigma q / \cos\beta\right) \cdot (l - x) \cdot x / l \cdot \Sigma H_x \quad (1.1)$$

The biggest defection occurs when the loaded bucket is at $x=\frac{l}{2}$:

$$f_{(l/2)} = \left(Q+n\cdot P'+0,5\cdot l\cdot \Sigma q/\cos\beta\right)\cdot l/4\cdot \Sigma H_{l/2} \qquad (1.1,a)$$

To determine deflection at the middle, the empirical formula can be used

$$f_{(l/2)} = \left(40+0,05\right)\cdot l/\sigma_v = \left(40+0,05\right)\cdot 200/1372 = 7,3m$$

or it can be determined through the diagram (Fig.7) with allowed deflection at the middle.

$$f^{d}_{(l/2)} = \left(0,03\div 0,08\right)\cdot l = \left(0,03\div 0,08\right)\cdot 200 = \left(6\div 16\right)m$$

Uniformly distributed load $\Sigma q$ is defined through the dependence

$$\Sigma q = \left(Q+n\cdot P'\right)\cdot C_q/\left[528+\left(0,66-0,5\cdot C_q\right)\cdot l\right] \qquad (1.2)$$

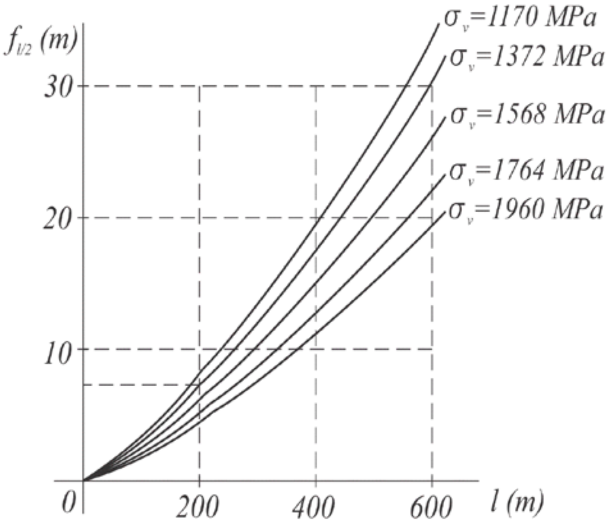

*Fig. 6 Total tensile forces at supports A and B*

where $C_q = 1{,}13$ - is the coefficient of cable crane with grabber.

After replacing the value in (1.2) we obtain the following:

$$\Sigma q = \left(56+3\cdot 0,49\right)\cdot 1{,}13/\left[528+\left(0,66-0,5\cdot 1{,}13\right)\cdot 200\right]$$

$$\Sigma q = 0{,}12\frac{kN}{m}$$

Rope weight $G$ is obtained from the expression:

$$G = l\cdot \Sigma q/\cos\beta = 200\cdot 0{,}12/0,9994 = 24kN$$

At the position where the loaded bucket is at the middle, horizontal tensile force in the system of ropes is:

$$\Sigma H_{(l/2)} = \left(Q+n\cdot P'+0,5\cdot l\cdot \Sigma q/\cos\beta\right)\cdot l/4\cdot f_{(l/2)} \qquad (1.3)$$

After substitution

$$\Sigma H_{(l/2)} = \left(56+3\cdot 0,49+0,5\cdot 200\cdot 0{,}12/0,9994\right)\cdot 200/4\cdot 7,3$$

$$\Sigma H_{(l/2)} = 476kN$$

Vertical tensile force at support A and B is determined from the formulas (1.4) and (1.5)

$$\Sigma V_{Ax} = Q\cdot\frac{l-x}{l}+n\cdot P'\left(1{,}5-\frac{x}{l}\right)+\left(\frac{l}{2\cos\beta}\right)\Sigma q\pm \pm\Sigma H_x tg\beta \qquad (1.4)$$

$$\Sigma V_{Bx} = Q\cdot\frac{x}{l}+n\cdot P'\left(0,5-\frac{x}{l}\right)+\left(\frac{l}{2\cos\beta}\right)\Sigma q\mp \mp\Sigma H_x tg\beta \qquad (1.5)$$

For $x=\frac{l}{2}$, it follows:

$$\Sigma V_{Ax} = 56\cdot\frac{200-100}{200}+3\cdot 0,49\left(1{,}5-\frac{100}{200}\right)+ +\frac{200}{2\cdot 0,9994}\cdot 0{,}12+476\cdot 0,035 = 58kN$$

$$\Sigma V_{Bx} = 56\cdot\frac{100}{200}+3\cdot 0,49\left(0,5-\frac{100}{200}\right)+\frac{200}{2\cdot 0,9994}\cdot 0{,}12- -476\cdot 0,035 = 25kN$$

Total tensile forces at supports A and B (Fig. 6) are:

- support A:

$$\Sigma T_{A(l/2)} = \sqrt{\left(\Sigma H_{(l/2)}\right)^2+\left(\Sigma V_{A(l/2)}\right)^2} = =\sqrt{476^2+58^2} = 479kN \qquad (1.6)$$

- support B:

$$\Sigma T_{B(l/2)} = \sqrt{\left(\Sigma H_{(l/2)}\right)^2+\left(\Sigma V_{B(l/2)}\right)^2} = =\sqrt{476^2+25^2} = 477kN \qquad (1.7)$$

The angles of rope deflection at supports A and B are defined from the following expressions:

$$\left.\begin{aligned} \alpha_{A(l/2)} &= arctg\frac{\Sigma V_{A(l/2)}}{\Sigma H_{(l/2)}} = \frac{58}{476} = 0{,}12\,rad \\ \alpha_{B(l/2)} &= arctg\frac{\Sigma V_{B(l/2)}}{\Sigma H_{(l/2)}} = \frac{25}{476} = 0,05\,rad \end{aligned}\right\} \qquad (1.8)$$

Loading of the bucket is done at the distance $x = 20m$.

Horizontal components of ropes are determined from the equation (1.9)

$$\left(\Sigma H_x\right)^3+\left(\Sigma H_x\right)^2\left\{E_uA_u\left[\frac{\cos^5\beta}{2l\left(\Sigma H_{(l/2)}\right)^2}\int_0^l\left(\Sigma Q_{b(l/2)}\right)^2dx\pm \pm\varepsilon\Delta t\cos\beta\right]-\Sigma H_{(l/2)}-E_uA_u\frac{\cos^5\beta}{2l}\int_0^l\left(\Sigma Q_{b(l/2)}\right)^2dx = 0\right. \qquad (1.9)$$

It can be assumed that $\Delta t = 0$.

Having in mind that

$$\int_0^l\left(\Sigma Q_b\right)^2dx = \left[Q\left(Q+2nP'+G\right)+nP'\left(nP'+2\frac{G}{3}\right)\right]\cdot \cdot\left(l-x\right)\cdot\frac{x}{l}+\left(nP'+G\right)^2\cdot\frac{l}{12} \qquad (1.10)$$

After replacement it follows:

$$\int_0^l \left(\Sigma Q_{bx}\right)^2 dx =$$

$$= \left[56\left(56+2\cdot 3\cdot 0,49+24\right)+3\cdot 0,49\left(3\cdot 0,49+2\frac{24}{3}\right)\right]\cdot$$

$$\cdot\left(200-20\right)\cdot\frac{20}{200}+\left(3\cdot 0,49+24\right)^2\cdot\frac{200}{12}=83130\,kN^2m$$

The expression (1.11)

$$\int_0^l \left(\Sigma Q_{b(l/2)}\right)^2 dx = \\ =\left[Q\left(Q+2nP'+G\right)/4+\left(2nP'+G\right)^2/12\right]\cdot l \qquad (1.11)$$

also implies that

$$\int_0^l \left(\Sigma Q_{b(l/2)}\right)^2 dx=\left[0,25\cdot\left(0,25+2\cdot 3\cdot 0,49+24\right)/4+\right.$$

$$\left.+\left(2\cdot 3\cdot 0,49+24\right)^2/12\right]\cdot 200=244500\,kN^2m$$

After replacing (1.10) and (1.11) into (1.9) the following equation is obtained:

$$\left(\Sigma H_x\right)^3+\left(\Sigma H_x\right)^2\left(1,6\cdot 10^8\cdot\frac{0,003232}{2\cdot 200\cdot 476^2}-244500\cdot 0,9994^5-\right.$$

$$\left.-476\right)-\frac{1,6\cdot 10^8\cdot 0,003232\cdot 0,9994}{2\cdot 200}\cdot 83130=0$$

After calculations, we get the final form of equation (1.10):

$$\left(\Sigma H_x\right)^3+915\left(\Sigma H_x\right)^2-107470464=0\,,$$

whose solution is:

$$\Sigma H_x=298\,kN$$

The vertical component of tensile forces of ropes at support A, when $x=20\,m$, is:

$$\Sigma V_{A(20)}=56\cdot\left(200-20\right)/200+3\cdot 0,49\cdot\left(1,5-20/200\right)+$$

$$+\left(0,5\cdot 200\cdot 0,12\right)/0,9994+298\cdot 0,035=75\,kN$$

The vertical component of tensile forces of ropes at support B, when $x=180\,m$, is:

$$\Sigma V_{B(180)}=56\cdot 180/200+3\cdot 0,49\cdot\left(0,5+180/200\right)+$$

$$+\left(0,5\cdot 200\cdot 0,12\right)/0,9994-298\cdot 0,035=54\,kN$$

Total tensile forces at supports A and B are:

$$\Sigma T_{A(20)}=\sqrt{298^2+75^2}=307\,kN$$

$$\Sigma T_{B(180)}=\sqrt{298^2+54^2}=303\,kN$$

Deflections of ropes are:

$$\alpha_{A(20)}=arctg\frac{75}{298}=0,25\,rad$$

$$\alpha_{B(180)}=arctg\frac{54}{298}=0,18\,rad$$

One of the columns and bucket on the loading position are shown on Fig.7 and Fig.8.

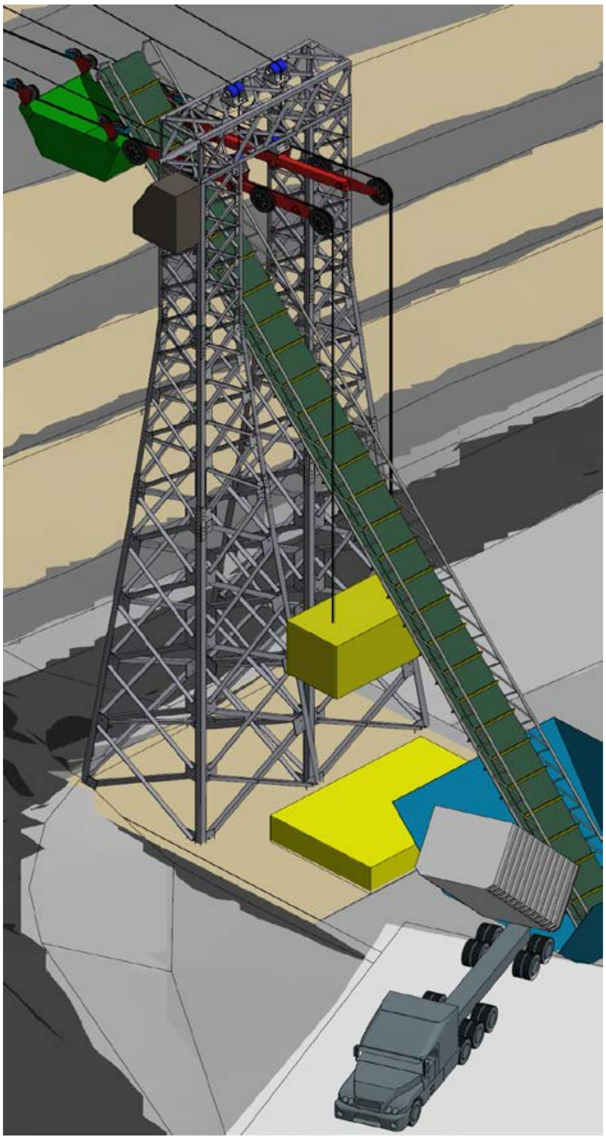

*Fig.7 Columns and bucket on the loading position*

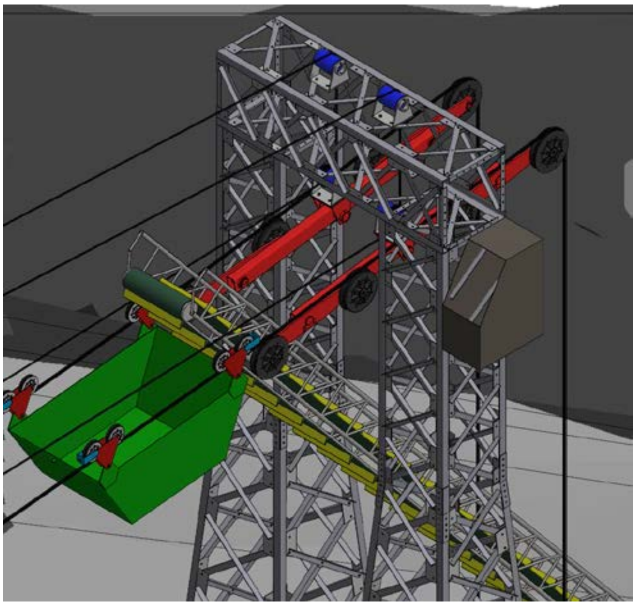

*Fig. 8 Bucket on the loading position*

## 3. CONCLUSION

Application of means of transport mechanization is an optimal concept of unloading and loading work at large landfills because:

- costs of transportation within the very area of the landfill are diminished,
- transportation trucks cannot be stuck in the area of the landfill,
- a large capacity of waste disposal can be achieved,
- dimensions of the landfill are not limiting parameters (length x width) for unloading and loading activities,
- after the landfill is closed, the means of transportation mechanization can be moved to a new location.

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