*Advance Researches in Civil Engineering*
*ISSN: 2645-7229, Vol.5, No.3, pages: 1-19*

# The Application of the Blast Preloading as a Potential Substitution or Companion for Surcharge and Vacuum in Weak Clay Treatment

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*(Date of received: 05/03/2023, Date of accepted: 14/06/2023)*

## ABSTRACT

*The rapid developments of infrastructures, especially in far less developed areas or in the coastal regions, necessitates new technologies to elevate the efficiency of the existing systems. One of the obstacles in such areas is the existence of weak soils that are not suitable at all for construction. Soil treatment process, especially in such areas, is very time consuming and expensive. The common method for land reclamation consists of application of prefabricated vertical drains (PVDs), surcharge with or without vacuum preloading. Even by applying vacuum preloading, the time needed for compilation of the project is still considered long. In this literature a new method is introduced as a new preloading agent to accelerate the soil treatment process and decrease the cost and time required for the compilation of the reclamation process. Blast preloading might be a substitution or a companion for existing methods. First, a case history was introduced and verified using finite element modeling (FEM) that includes surcharge and vacuum preloading. Then the blast was applied to verified models, and the efficiency of it was investigated for every possible situation. It was shown that blast preloading has the potential to be used in soil treatment systems, as the required time was halved in many cases and the settlement increased from 20 to 50 percent, in comparison to cases without blast preloading. Even in cases in the absence of surcharge or vacuum, the blast preloading acts the same as surcharge or vacuum. Although it should be noted that it is still a preliminary investigation, more extensive lab and field tests are required for adoption of blast preloading as a new technique in soil treatment systems.*

**Keywords:**

*Blast, Vacuum, Surcharge, PVD, Clay.*

## 1. Introduction

Vacuum preloading is widely used nowadays as an efficient method to accelerate the consolidation process in weak and soft clays [1-3]. The vacuum preloading is applied mostly in companion with surcharge embankments. Regarding the difference between soil treated by surcharge and vacuum, [4] conducted a series of lab test by means of cyclic loading, and concluded that the samples that were consolidated by vacuum showed less anisotropy of permeability compared to those that were preloaded with surcharge. The vacuum is transferred to soil layers by means of PVDs. New technologies and methods are now in progress to facilitate the transition process more efficient and reliable, to decrease the treatment process more economical than before, like the application of air booster [5] and air blowing technique [6, 7], the application of thermo- vacuum – PVD [8] , combined application of vacuum preloading–variable spacing electro-osmosis [9] ,the combination of electro-osmosis and with dynamic compaction method with vacuum preloading [10] , the combination of vacuum and dynamic compaction[11] or using new PVDs with modified patterns[12]. All the stated methods aim to increase the water discharge between PVDs, especially in smear zone[13, 14], and also to decrease the required time to achieve the predefined degree of consolidation[15] in soil treatment designation. The analysis of soil response under blast loading is different from those that are found in the general concepts of soil mechanics or soil dynamics. In the latter, it has been assumed that solid particles are rigid and pore fluid incompressible in accordance with the effective stress principle. Later, Biot developed the theory of poro-elasticity (Biot theory) [16, 17] in which both the solid grains and porous skeleton were assumed to be elastic, and the pore fluid flowing in interconnected voids is also compressible through complex coupling mechanisms, while the deformation of the system has been assumed infinitesimal [18] . These assumptions on the compressibility of phase components were also adopted later in the generalized Biot's theory for nonlinear material behaviour, whilst the fluid–solid interactions have been generally simplified by neglecting the relative accelerations of the fluid phases with respect to the solid phase [18]. This is because solid particles will be compressible in this condition, and the trapped fluid phase(s) will simultaneously deform with the soil skeleton in a highly nonlinear manner, thus providing additional resistance which could possibly be even more significant than that of the matrix for the soil when subjected to blast loading with high amplitude. This can be due to the hypothesis that interstitial fluids with even higher stiffness are not able to drain during blast loading [18-21], and thus Biot theories that incorporate fluid flow are also generally not used in the modelling of blasting. Furthermore, under transient blast loading, the effects of high strain-rates should be considered as a crucial factor on the stiffness, strength and other mechanical behaviours of the soil [18]. [22] had investigated Influence of particle size distribution on the blast pressure profile from explosives buried in saturated soils. Base on the test that has been carried out the following result were obtained: 1) No fundamental difference in loading mechanisms between cohesive and cohesion less soils 2) Particle size has no significant effect on loading mechanism 3) Localized variations in loading are inversely proportional to uniformity of the soil 4) A well-graded soil (with particles over 10 mm) will demonstrate considerable localized particle strikes in the region directly above the charge which gives rise to a more centralized loading distribution when compared to more uniform soils. [23] conducted a numerical investigation on the effect of water saturation on propagation of blast waves in soil structure and concluded that a small amount of air in soils could significantly affect the blast wave parameters. For example, with 4% volume of air, the peak pressure in the soil could reduce by 1–2 orders of magnitude as compared to water-saturated soils within a scaled range of 0.5–4.0 (m kg ^ -1/3), while the peak particle velocity reduces by 2–6 times. Regarding the formation of the crater [24] state that The sizes of the soil craters increased as the depth of the explosive increased. The crater depth and slopes were significantly affected by soil type. The clay craters had the greatest depths and the steepest side slopes for all charge positions while the sand craters had the shallowest depths and flattest side slopes. The application of blast loading in soil treatment systems is mainly focused on sands and gravels as it can be seen in fig 1, to trigger the liquefaction [25-27] and, as an agent for the densification [28, 29] of soil layers. In fine grained soil, as a result of strong bonds between microscopic water layers and ionic interconnection of soil particles and diffuse double layers [30], the applied stress don't transfer to grain particles and accumulate in water layers. As a result, the applied stress by blast would only cause the increment in excess pore water pressure and no settlement occurs in contrast to soil with granular structure. The stated increment in excess pore water pressure has the potential to be used as a factor in acceleration of the consolidation when combined with PVDs. There is patent, that use the surface dynamic heavy tamping[31, 32] in conjunction with the placement of explosive in the depth between 8 to 18 m for deep compaction and vacuum for dewatering of the ground water for soft soil stratum in large areas [33]. Until now there was no field or numerical or analytical study that utilized blast as a preloading agent like surcharge or vacuum preloading, was not done. This article aims to simulate the process of surface blast as a preloading agent in companion or potential substitution for vacuum and surcharge preloading in a verified finite element (FE) case history model. This simulation is only a start for future lab and small scaled experiments, and the outcome of the simulation should be investigated precisely in the future for necessary modifications.

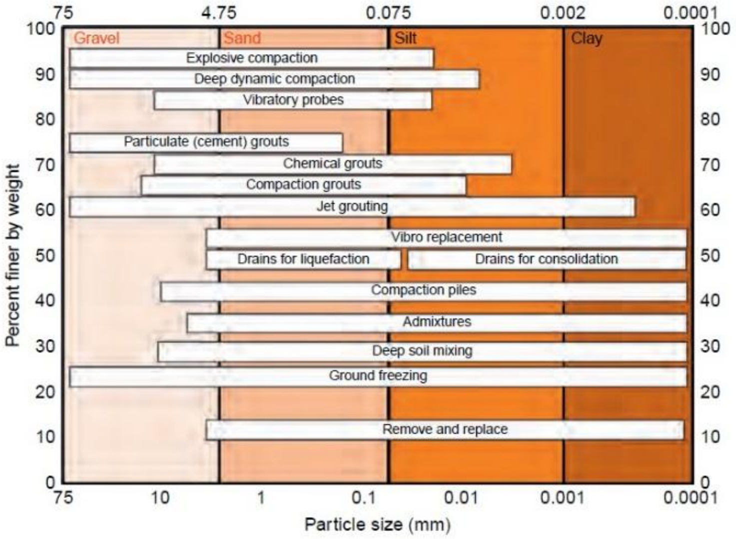


**Figure 1.** soil improvement methods applicable to different range of soil [34].

## 2. Materials and methods

### *2.1. The verification of the cast study*

Bangkok airport is the case study that would be investigated here. The soil of the project has low strength and high compressibility issues, and a vast reclamation program was planned that includes the utilization of PVDs, vacuum preloading, stone columns, surcharge preloading and so on [35]. In order to investigate the efficiency of the proposed treatment designation, various pilot areas were instrumented and the proposed soil treatment systems were constructed on a small scale. Three trial embankments were built as TS1 with 1.5 m PVD spacing, TS2 with 1.2 m PVD spacing and TS3 with 1 m PVD spacing to examine the performance of the system of combined surcharge and PVDs in various patterns. TV2 was one of the embankments that was built to investigate the efficiency of applying vacuum preloading along with embankments as surcharge preloading agents and PVDs. Figure 2 shows the soil parameters at the project. The PVD drains were installed to a depth of 12 m. The embankments for TS1, TS2 and TS3 were constructed to a height of 4.2 m with 3H: 1V side slopes. For TV2 the embankment height was 2.5 m. A one-meter thick sand blanket was placed on the site as a construction working pad [35]. The drains were installed from on top of the sand pad. The sand blanket was presumably also included in the FE model, to ensure that there would be no build-up of excess pore water pressures, at the base of the embankment, and to drain away any water being squeezed out of the clay. The applied vacuum pressure and the construction sequence of the embankment is shown in fig 2. Supplementary information on the project site can be found in [35].

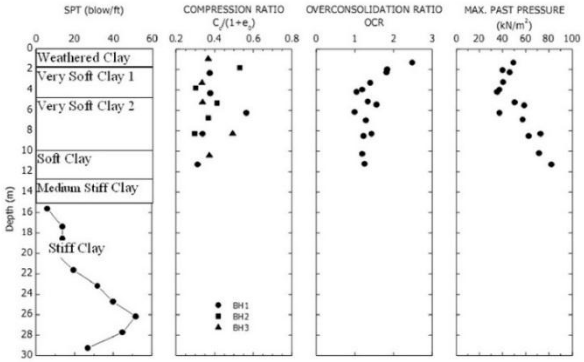
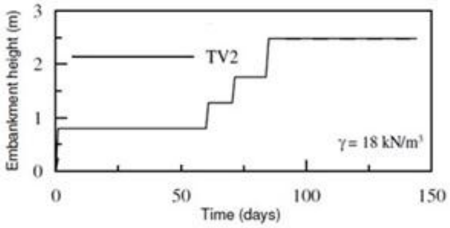


**Figure 2.** soil parameters in Bangkok airport [36].



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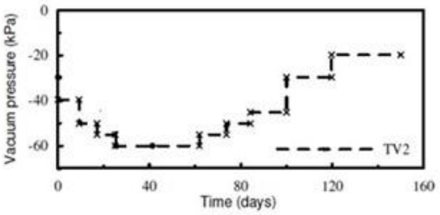


(b)

**Figure 3.** The construction process of preloading in Bangkok TV2 (a)Sequential placement of surcharge embankment vs. time (b) vacuum pressure application vs. time [37].

The modified cam clay model for FEM was used, as its efficiency is proven in such complex model by different researchers [38-42]. Geostudio 2018 Sigma/W coupled analysis with sequential embankment loading was used for modelling the consolidation process in the soil treatment. The modelling of the TV2,TS1,TS2 and TS3 was done before by the authors , for detailed specification of the modelling procedure, data's can be found in [43, 44]. The verification of the models with and without vacuum preloading for TS1, TS2, TS3 and TV2 is shown in fig 4 and 5. As it can be seen in figure 4, the FEM results slightly overestimated the pass, but the final settlement was predicted according to field instrumentations. As the distance between PVDs increases, the results become more overestimated in the curve path. This might be the result of delayed consolidation of natural clays due to the degradation and reconstitution of the structure as pointed out by [45, 46]. As the distance between PVDs increases, the delayed consolidation becomes more notable. For the case with vacuum preloading, this phenomenon is less pronounced that shows the efficiency of vacuum preloading in such soil treatments.

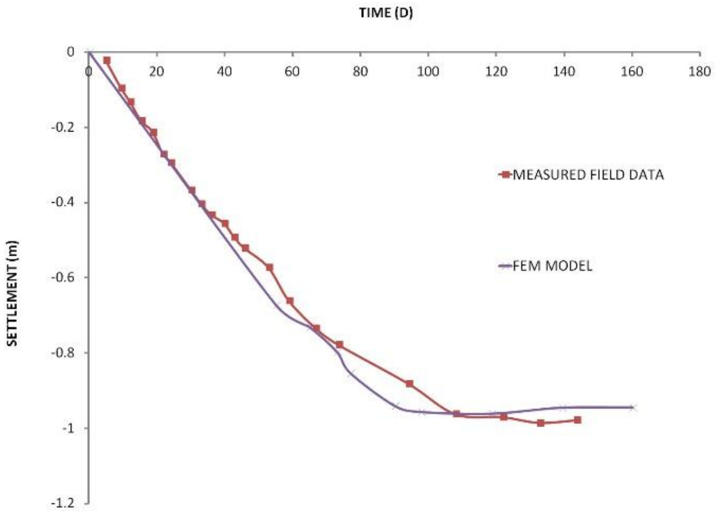
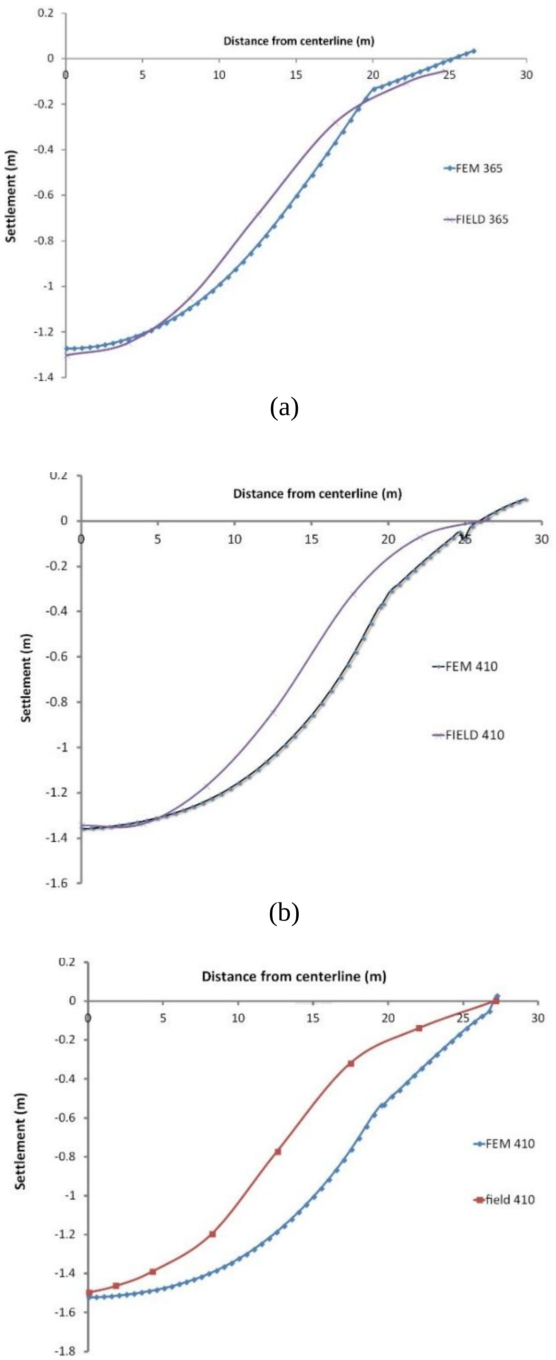


**Figure 4**. the verification of the embankment TV2 vs. measured data at site ( measured data from [47]).



(a)

(b)

(c)

**Figure 5.** The FEM results for verification of (a) TS1 settlement after 365 days (b) TS2 settlement after 410 days (c) TS3 settlement after 410 days, at the centreline of the embankment vs measured data's , field measured data's from [36].

### *2.2. The application of blast to the verified models*

Stiff reduction curve for dynamic parameters needed for FEM was derived from [48, 49] that performed extensive odometer and triaxial tests and analytical investigation on Bangkok clay that is shown in Figure 6.

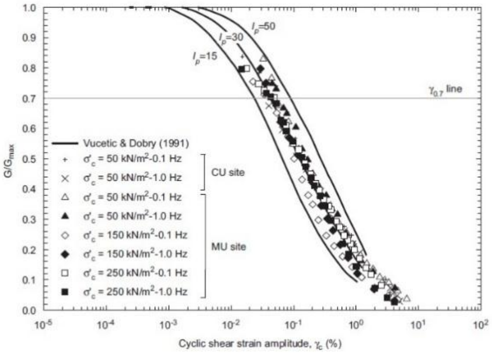
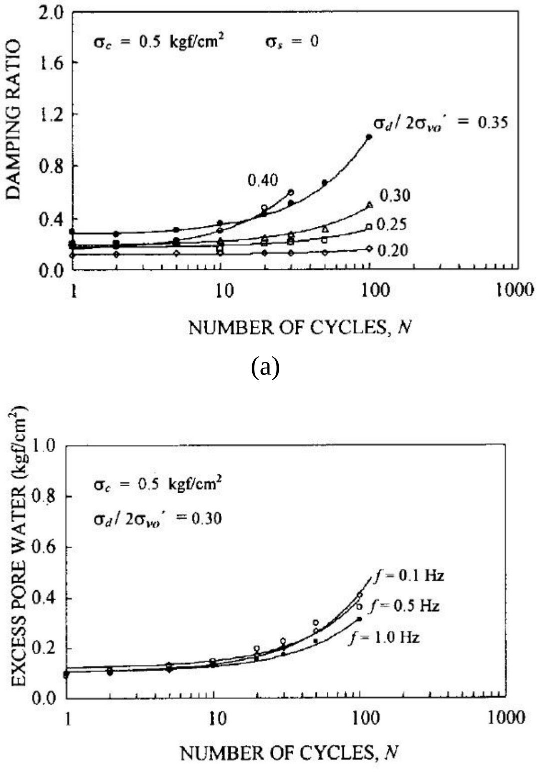


**Figure 6.** stiff reduction curve for soft Bangkok clay [49].

The damping curve vs loading cycles and also the excess pore water pressure vs number of cycles, was derived from [50], that used cyclic triaxial tests on Bangkok clay for determination of behaviour of strength and pore water generation under cyclic loading. The damping curve vs loading cycles and excess pore water generation curve vs cyclic loading are shown in Fig 7.

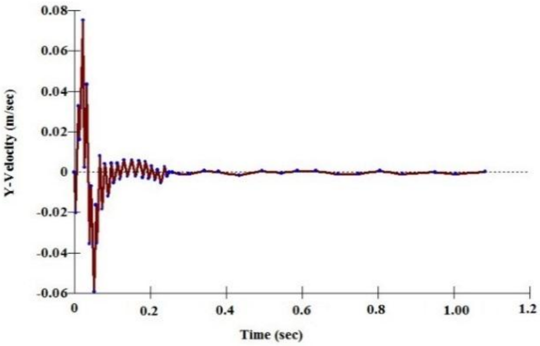


(a)

(b)

**Figure 7.** (a) effect of loading frequency on excess pore water generation (b) shear modulus and number of cyclic loading, of Bangkok clay [50].

Any dynamic load can be simulated by displacement, velocity or acceleration. In this article the velocity was used for FEM in Quake/w. The blasts that were used in the analysis are shown in fig 8. Geostudio integrates the area under the velocity curve to obtain the displacement versus time function and the blast causes a sudden displacement on the model surface that as a result simulates the blast preloading. As it is shown in fig 8, the magnitude of y displacement of one of the blasts is 10 times greater than the other for comparison. The blast curve that was modified for FEM, was taken from [51]. By defining a history point in the blast area, the maximum velocity of 0.075 m/sec and 0.0075 m/sec was obtained in the y-axis, for defined blast loads.



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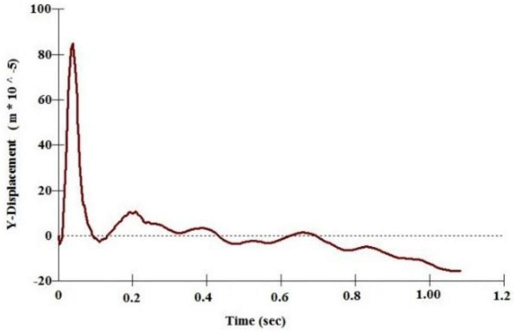

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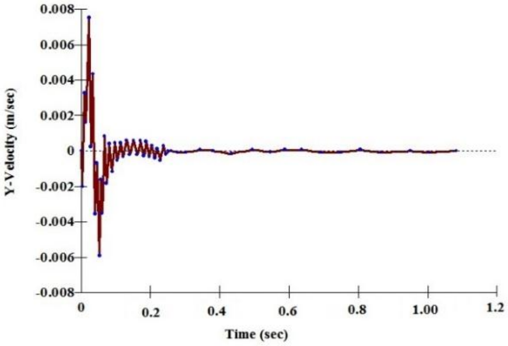

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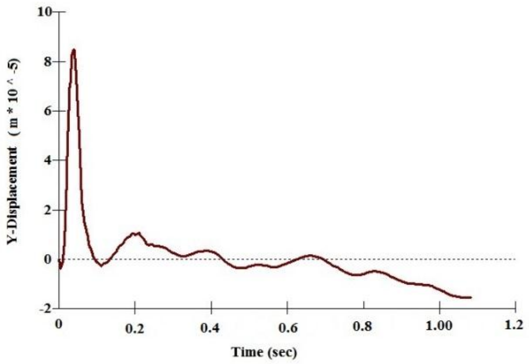

(d)

**Figure 8**. The Y-Velocity and Y-Displacement curves of applied blast versus time (a) and (b) the blast with the maximum velocity of 0.075 m/sec, (c) and (d) the blast with the maximum velocity of 0.0075 m/sec.

Geostudio 2018 has the ability to transfer the FEM results between its suites. First the blast was applied in Quake/w on the soil stratum of the verified model and then, the models were transferred to Sigma/w patch for application of sequential embankment and applying vacuum preloading to investigate the efficiency of the blast based on the verified models. The equivalent linear model was used in dynamic analysis. The equivalent linear model is similar to the elastic model but in the equivalent linear model the soil stiffness module (G) is modified based on the calculated strains for every step. It should be noted that since in blast preloading, very high strains are transferred in a very short period of time, as stated by [52], the reduction of $G_{max}$ increases suddenly and remarkably when the effective stresses degrade to a certain degree. As a result, even cyclic tests in labs are somehow overestimating the $G_{max}$ for such cases as blast preloading, but for numerical simulations the accuracy is adequate. A schematic image after the application of the blast to the soil stratum of the defined case history is shown in Fig 9.

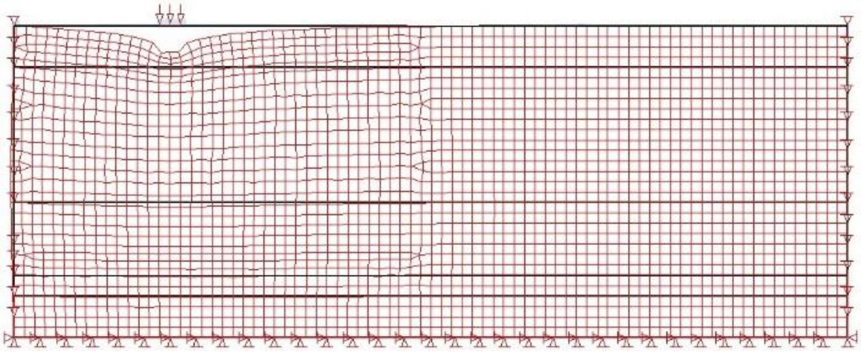

**Figure 9:** The schematic view of the boundary condition and the creation of crater as a result of blast in Quake/W.

## 3. Discussions and Results

According to [53], there are two basic types of deformation that exist in soils: the first is the deformation of the solid skeleton, while the second is the deformation of all soil phases namely : 1) The elastic deformations of bonds on the contact surfaces of particles at low pressure; and, at high pressures, a failure in bond and displacements of the particles and 2) The deformation of all the soil phases, determined by their volume compression [23]. For dry soils which contain a lot of air and a small amount of water, the compressibility of the voids exceeds considerably that of the skeleton; thus, the initial deformation will be dominated by the first mechanism. With increasing pressure, the soil gets compacted such that the second mechanism becomes more and more important. In water-bearing soils, on the other hand, the voids are filled with a lot of water and a little air. Hence, when loading is static or at a low rate, the water and air will be pressed out of the voids and the compressibility is mainly controlled by the solid skeleton. With a rapid dynamic loading, however, the water and air will exhibit higher resistance than the bonds between the solid particles due to the fact that there is not enough time for the air and water to flow through the soil skeleton. As a result, the deformation and resistance will be dominated by the second mechanism, particularly by the water and air deformation while the deformation of the solid phase only becomes effective at high pressure such as in the case of shock loading [23]. Their dominance is determined by the constitution of the phase components as well as the magnitude of pressure (or distance from the charge). Specifically, the former is found at low pressures for dry soils, whilst the latter prevails at high pressures and in water-bearing soils. In fact, for water-bearing soils, the inter-particle friction is quite low, thus the second type of deformation is more prevalently found, while the first type of deformation is less important and is significant only at extremely high pressures[18]. Meanwhile, with increasing distance to a charge, the blast waves gradually attenuate and the soil also undergoes less compression. Therefore, the second type of deformation or the deformation of all soil phases is more prevalent in the vicinity of the camouflet, while the first type of deformation, that is, the deformation of the soil skeleton, is more dominant further away from the explosion [18, 20, 54]. Given the fact that there is simultaneous deformation in all three constituent phases during blast loading, an applicable material model should include the compressibility of each phase, and be able to reproduce the different types of deformation of soils in the course of the blast event [53]. In addition, due to the high pressure exerted onto soils, their deformation will no longer be linear[18]. In fact, under the perception that all soils exhibit similar contractive behaviour during intensive blast loading, only the effect of (relative) density, degree of saturation, and stiffness on blast response of soils have been experimentally investigated to date, while other controlling factors such as soil type, over consolidation ratio, and anisotropy have been generally disregarded [18]. The mentioned items are exactly the main influencing parameters in weak clays, that were neglected so far as a result of limited investigation regarding blast effect on fine grained soil, unlike the vast experiments regarding coarse grained soils. In the meantime, due to the intensity and destructive nature of blast tests, very few parameters, such as total and pore pressure as well as particle velocity, can be measured, and thus very limited details of the constitutive behaviours of soils can be provided for model development and validation purposes. As a result, soil models have been generally developed on a phase basis and applied to assess its blast response regardless of the differences in soil type and a few other properties[18]. Based on the verified models, different cases were modelled and the results are presented in the next section. The soil treatment systems for weak clays are often the combination of surcharge and vacuum as preloading agents and PVDs. in this study the effect of blast is included as a new or a companion as a preloading agent. The scenarios are divided in two parts as: scenarios including vacuum preloading and, scenarios excluding vacuum preloading. In fig. 10, based on the verified models, hypothetical cases are modelled and presented in one diagram for comparison and, as a basis for further modelling to investigate the effectiveness of blast as a preloading agent.

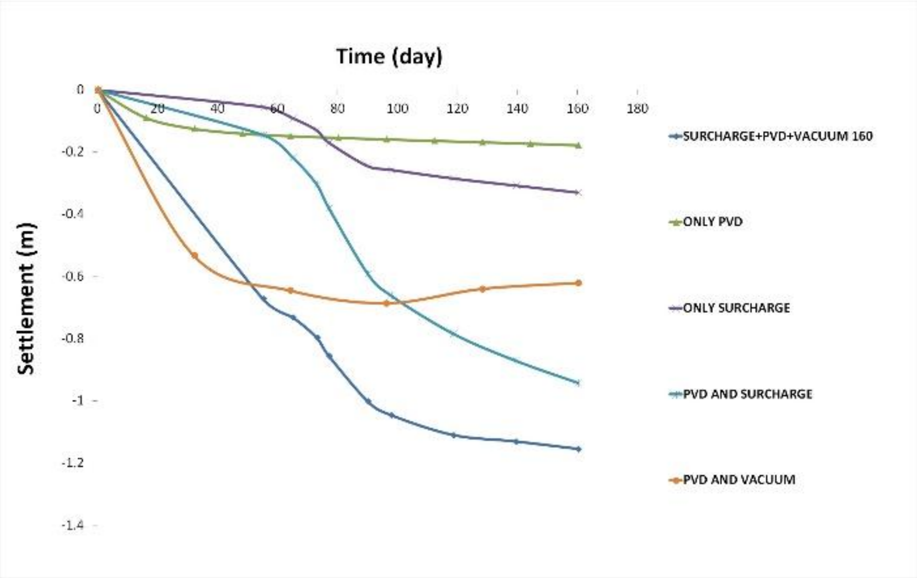

**Figure 10**. the hypothetical models of different cases of soil treatment systems base on the verified models.

In fig 10 , it can be seen that the least settlement belong to the application of PVD alone, and the second small settlement is the case with application of the surcharge alone. The consolidation that occurred in PVD alone case, is the result of increased vertical and horizontal permeability that caused a 0.18 cm consolidation. The consolidation in surcharge alone after 160 d, was 0.33 cm while in the case of combination of PVDs as a means to ease the water discharge and surcharge as a preloading agent, the settlement increased to 0.94 cm. As it can be seen these systems individually have a very low efficiency, while when combined with each other, they show magnificent results. The application of vacuum and PVDs in the absence of surcharge as the second preloading factor yielded the settlement of 0.68 cm, while in combination with surcharge, the settlement increased to 1.15 m. There is a heave in the settlement curve that is related to decrease in applied vacuum pressure after 90 days that was also reported by [55]. The combination of surcharge and PVDs works better than the combination of PVDs and vacuum and if this chart was obtained in real the field it was obvious that in this specific project, the system of surcharge and PVDs is more economical and superior and is the number 1 choice for soil treatment system. The only condition that the application of vacuum preloading can be considered is the importance of project's scheduling, which is the case in many projects with similar conditions.

### *3.1.Scenarios excluding vacuum preloading*

#### *3.1.1. The cases with surcharge and blast preloading*

With the application of blast preloading, the settlement was increased from 0.33 cm to 0.35 with the blast with the maximum velocity of 0.0075 m/sec and 0.43 cm settlement, with the blast with the maximum velocity of 0.075 m/sec (fig 11). There was no significant improvement in applying blast preloading in the absence of PVDs regarding final settlement, but the time needed for 0.33 m settlement halved for the blast with the maximum velocity of 0.075 m/sec.

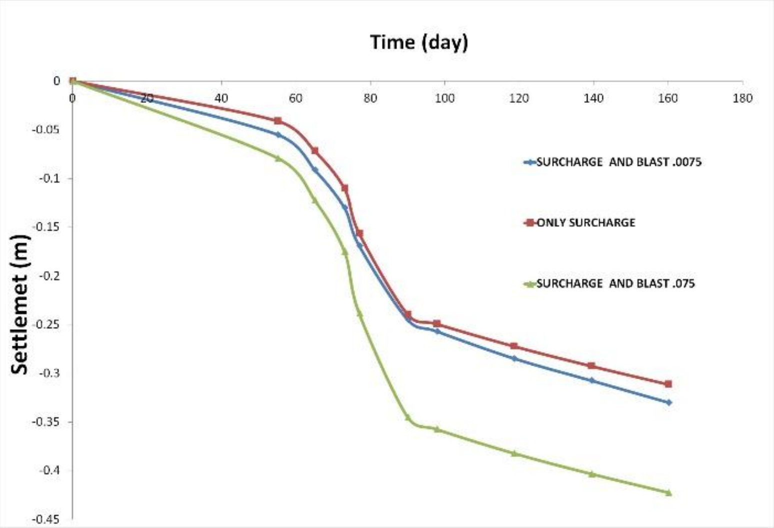

**Figure 11.** The settlement curves of scenarios of only surcharge, surcharge and blast with the maximum velocity of 0.075 m/sec and surcharge and blast with the maximum velocity of 0.0075 m/sec after 160 days.

### *3.1.2. The cases with PVDs and blast*

As it can be seen in fig 12, the application of blast with the maximum velocity of 0.075 m/sec and .0075 m/sec, has increased the settlement from 0.18 cm to 0.43 cm and 0.57 cm respectively. The blast acted like a 1.25 m surcharge embankment and the overall system efficiency was raised considerably, and the magnitude of the settlement was 2.38 and 3.16 times greater than the preliminary case. The 0.18 m settlements were reached in less than 20 days for cases including blast preloading.

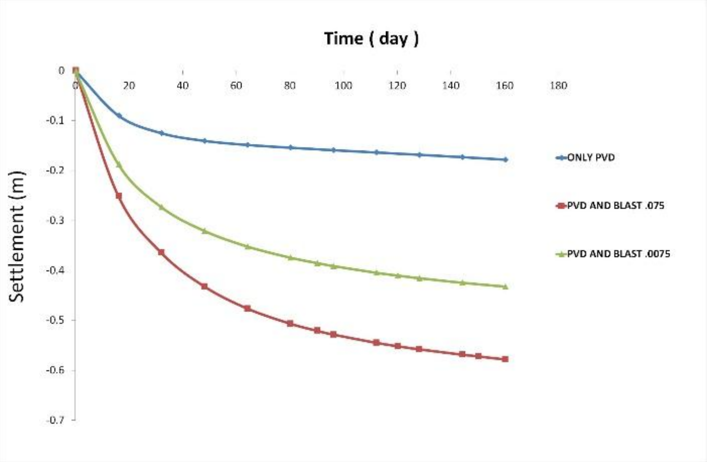

**Figure 12.** The settlement curves of scenarios of only PVDs, PVDs and blast with the maximum velocity of 0.075 m/sec and PVDs and blast with the maximum velocity of 0.0075 m/sec after 160 days.

### *3.1.3. The cases with surcharge and PVDs and blast*

By the inclusion of blast in the case with PVDs and surcharge, the settlements increased from 0.94 m to 1.24 m and 1.41 m for the blasts with the maximum velocity of 0.075 m/sec and .0075 m/sec respectively as illustrated in fig 13. The resultant settlements are even greater than 1.15 m that was gained through the application of vacuum preloading combined with surcharge and PVDs. The FEM results show that the blast preloading has the potential to be a substitution for vacuum preloading. Regarding the time, the consolidation settlement of 0.94 m was reached in only 84 days for the blast with the maximum velocity of 0.075 m/sec and in 93 days for the blast with the maximum velocity of 0.0075 m/sec. The required time for the 0.94 m settlement was approximately halved in comparison to case without blast preloading.

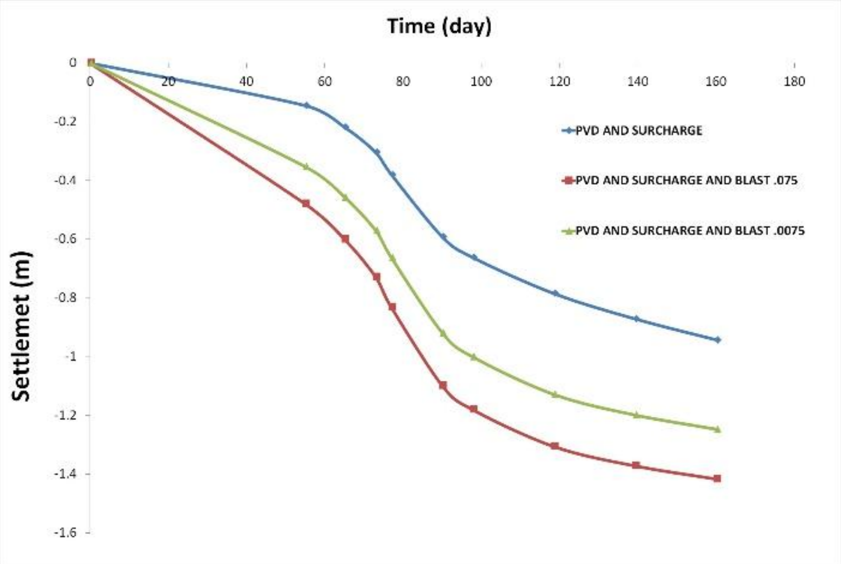

**Figure 13.** The settlement curves of scenarios of PVDs and surcharge, PVDs and surcharge and blast with the maximum velocity of 0.075 m/sec and of PVDs and surcharge and blast with the maximum velocity of 0.0075 m/sec after 160 days.

## *3.2. Scenarios including vacuum preloading*

### *3.2.1. The cases with PVDs and vacuum and blast*

In this case the application of PVDs, vacuum and blast preloading was investigated. As it is illustrated in fig 14, the maximum settlement increased from 0.68 m to 0.95 m and 1.14 m for the blasts with the maximum velocity of 0.075 m/sec and .0075 m/sec respectively. The settlement for the case with combined vacuum, surcharge and PVDs was 1.15m. The blast with the maximum velocity of 0.0075 m/sec combined with vacuum and PVDs, had the same settlement as the case with surcharge and PVDs that is 0.95 m settlement consolidation. By applying the blast with the maximum velocity of 0.075 the same result was obtained in a situation where there was not a 2.5 m surcharge preloading. By considering the FEM results, it can be concluded that the blast with the maximum velocity of 0.075 had the same effect as surcharge and can be substituted for as a new preloading agent. Regarding the required time, the settlement of 0.68 m was obtained in only 23 days for blast with the maximum velocity of 0.075 m/sec and in 32 days for blast with the maximum velocity of 0.0075 m/sec.

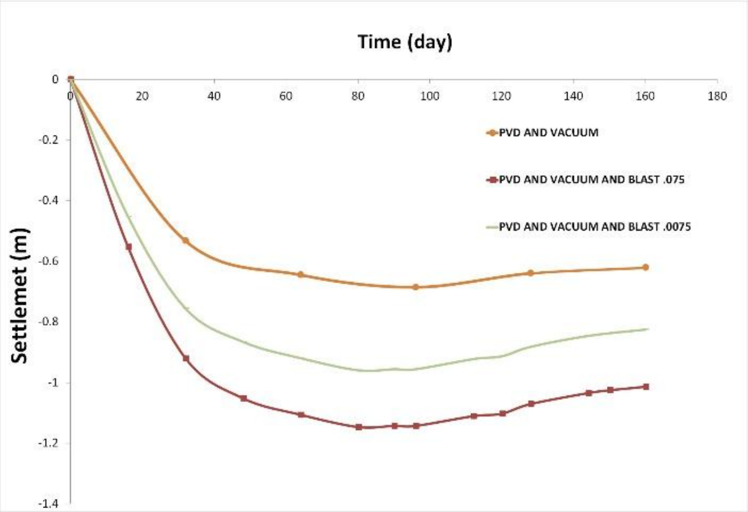

**Figure 14.** The settlement curves of scenarios of PVDs and vacuum, PVDs and vacuum and blast with the maximum velocity of 0.075 m/sec and PVDs and vacuum and blast with the maximum velocity of 0.0075 m/sec after 160 days.

### *3.2.2. The Cases with PVDs and vacuum and surcharge and blast*

By applying the blast in a case that combines surcharge, vacuum, PVDs and surcharge preloading, the maximum results were obtained, which is illustrated in fig 15. For the blast with the maximum velocity of 0.075 m/sec and 0.0075 m/sec, the consolidation settlements of 1.49 and 1.73 m were obtained respectively. The settlement in the absence of the blast was 1.15 that is the settlement recorded for TV2 in Bangkok. By applying the blast preloading, the final settlement was increased to 29 and 50 percent in 160 days. The advantage of blast preloading in this case study is mainly related to the time saving that happened, as for the blast with the maximum velocity of 0.075 m/sec, the 1.15 settlement was reached in only 50 days (less than 1/3 160 days), and for the blast with the maximum velocity of 0.0075 m/sec, it was reached in only 71 days that is fabulous. Apart from increasing the settlement and decreasing of soil treatment operation, the surficial explosion can also be used for the omission of weak and organic layers that exist before the start of the project. Regarding the application of explosive charge on the surface or in the mid layer of the target layer or even the combination of both buried and surficial explosion, further investigation is needed, especially in the case where the blast is meant to be used as a preloading agent.

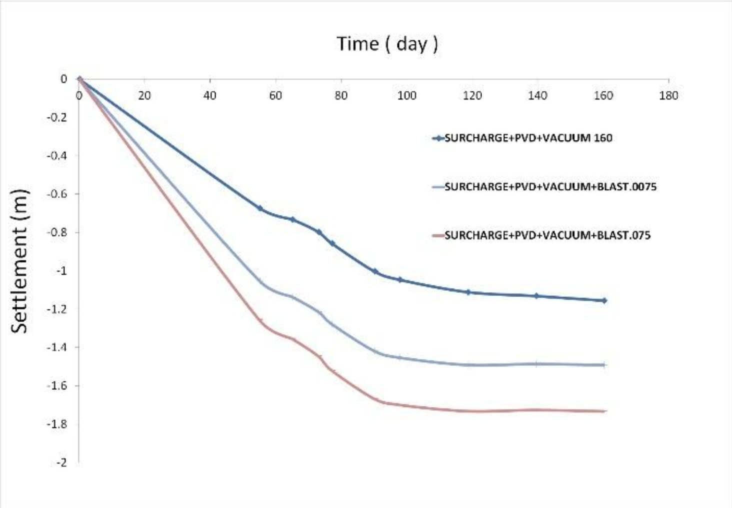

**Figure 15**. The settlement curves of scenarios of surcharge and PVDs and vacuum, surcharge and PVDs and vacuum and blast with the maximum velocity of 0.075 m/sec, and the case with surcharge and PVDs and vacuum and blast with the maximum velocity of 0.0075 m/sec after 160 days.

## 4. Conclusion

A case history including surcharge and vacuum preloading was introduced and verified. Two blasts were defined with the maximum velocity of 0.075 m/sec and 0.0075 m/sec. The blasts were applied to the verified models, and based on the verified FE models, different scenarios were introduced as cases including vacuum preloading and cases without vacuum preloading. For the cases without consideration of vacuum preloading, FEM was done for 1) The cases with surcharge and blast preloading, 2) The cases with PVDs and blast preloading and 3) The cases with surcharge and PVDs and blast preloading. Regarding the cases with surcharge and blast preloading there was no significant improvement in applying blast preloading in the absence of PVDs regarding final settlement, but the time needed for 0.33 m settlement halved for the blast with the maximum velocity of 0.075 m/sec. For the case that includes PVDs and blast preloading, the 0.18 m settlements were reached in less than 20 days for cases including blast preloading and the magnitude of the settlement was 2.38 and 3.16 times greater than the preliminary case. For the cases with surcharge and PVDs and blast, the consolidation settlement of 0.94 m was reached in only 84 days for the blast with the maximum velocity of 0.075 m/sec and in 93 days for the blast with the maximum velocity of 0.0075 m/sec. The resultant settlement is even greater than 1.15 m that was gained through the application of vacuum preloading combined with surcharge and PVDs. The FEM results show that the blast preloading has the potential to be a substitution for vacuum preloading. For the cases including vacuum preloading, FEM was done for 1) The cases with PVDs and vacuum and blast preloading and 2) The cases with PVDs and vacuum and surcharge and blast preloading. Regarding the cases with PVDs and vacuum and blast preloading, the blast with the maximum velocity of 0.0075 m/sec combined with vacuum and PVDs, had the same settlement as the case with surcharge and PVDs that is 0.95 m settlement consolidation. By applying the blast with the maximum velocity of 0.075 the same result was obtained in a situation where there was not a 2.5 m surcharge preloading. By considering the FEM results, it can be concluded that the blast with the maximum velocity of 0.075 had the same effect as surcharge and can be substituted for as a new preloading agent. Regarding the required time, the settlement of 0.68 m was obtained in only 23 days for blast with the maximum velocity of 0.075 m/sec and in 32 days for blast with the maximum velocity of 0.0075 m/sec. For the cases with PVDs and vacuum and surcharge and blast preloading, by applying the blast preloading, the final settlement was increased to 29 and 50 percent in 160 days. The advantage of blast preloading in this case study is mainly related to the time saving that happened, as for blast with the maximum velocity of 0.075 m/sec, the 1.15 settlement was reached in only 50 days, and for the blast with the maximum velocity of 0.0075 m/sec, it was reached in only 71 days that is great amount of saving in the time and overall project cost. As it can be seen, the application of blast as a preloading agent, has a fabulous effect in the raising of the efficiency of the project, and it has the potential of being applied both as a companion and/or as a substitution for vacuum or surcharge.

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