Application of dynamic replacement & mixing method for Sabkha treatment

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Abstract. For ground improvement of weak material, a developed method from dynamic replacement & mixing was applied on red sea village development project located in Jeddah, KSA. Test results revealed such method obviously improved the property of intermediate soil compared to traditional dynamic replacement.

1. Introduction
Dynamic replacement (DR) is a widely used method for ground improvement developed by Menard and Broise[1]. The principle of dynamic replacement is dropping a heavy weight on to the ground surface to punch large pillars of imported granular fill into the ground[2]. The inserted granular fill pillar will give strong support to surface blanketing layer to provide a stable ground. However, due to the mechanism of dynamic replacement, the replacement layer is not uniform. Such characteristic brings challenge to future embedded structure or utilities construction.

The Red Sea Village Development project gives a high-performance requirement on treated Sabkha soft layer. To meet project requirement, a new method was developed based on dynamic replacement named dynamic replacement & mixing.

2. Project background
2.1. Ground condition
The Red Sea Village Development project is located at Salman Bay area, Jeddah, KSA. Affected by specific geography and climate[3], with long-term evolution, the site ground is covered by an around 2m thick Sabkha layer. This type of soil has characteristics of low bearing capacity, low strength, and large change in its volume and consistency and, thus, poses many geotechnical problems to structures and infrastructures[4]. Series lab tests were conducted on site Sabkha specimen to show its properties.

| Water Soluble Sulfates (%) | Water Soluble Chlorides (%) | Liquid Limit | Plasticity Limit | Plasticity Index |
|-----------------------------|-----------------------------|--------------|------------------|-----------------|
| 0.436                       | 3.140                       | 61           | 32               | 29              |

Table 1. Properties of Sabkha prior treatment
Prior ground improvement, CPT was carried out to identify detailed Sabkha layer. Test result indicates that Sabkha layer is existing at around -1.5~0.8m.

* From top of Sabkha layer up to +2.1m is temporary platform for test equipment accessing.
2.2. Project requirement
Project requests filling up to +2.0~+6.0m, meanwhile treating Sabkha layer and filling layer. After
ground improvement, project requires CPTs shall conform a minimum cone tip resistance of 8MPa
unless notable silt or clay deposits are encountered, i.e., material with fines greater than 10%, whereby
a reduced minimum cone tip resistance of 1.5MPa and friction ratio of 5% will be accepted.

3. Ground improvement trial
Both dynamic replacement and dynamic replacement & mixing method were designed and applied on
trial. Prior ground improvement, above Sabkha layer, Engineering Fill will be placed up to +2.0m and
compacted by roller as a working platform. Consider both Sabkha layer and filling layer, the treatment
depth is 3.5m.

| Table 2. Properties of Engineering Fill |
| Sieve size, mm | 125 | 90 | 2.0 | 1.18 | 0.60 | 0.063 |
| Passing, %      | 100 | 85~100 | 40~100 | 25~100 | 0~75 | 0~10 |

3.1. Dynamic replacement (DR)
Dynamic replacement was conducted with 23.5t hammer (1.8m x 1.8m, octagon).
- Grid spacing, 3.5m.
- Including 3 phases, each phase has 2 passes.
- Pass 1 lifting height, 10m.
- Pass 2 lifting height, 15m.

![Figure 3. Pattern of dynamic replacement.]

During dynamic replacement, when crater depth achieves hammer height (1m), fill the crater with
gravel material. Each stage will be stopped when average settlement of last two drops less than 10cm.

| Table 3. Properties of replacement gravel |
| Sieve size, mm | 75 | 37.35 | 26.5 | 19 | 9.5 | 4.75 | 2.36 | 1.18 |
| Passing, %      | 100 | 30~100 | 0~100 | 0~50 | 0~30 | 0~15 | 0~10 | 0~5 |

3.2. Dynamic replacement & mixing
After dynamic replacement method, increase a new stage. Tamping intermediate soil by same hammer
with lifting height 15m. The high energy tamping of intermediate soil will force soft material rise to
ground mixed with replacement gravel and platform Engineering Fill along the gravel pillar. During
this stage, when crater depth achieves hammer height (1m), fill the crater with surface mixed material (no extra imported material required). Name this stage as dynamic mixing.

Figure 4. Concept of dynamic mixing.

This stage will be stopped when average settlement of last two drops less than 10cm.

Figure 5. Pattern of dynamic replacement & mixing.

4. Trial Result

4.1. Dynamic replacement
CPT has been carried out to verify the result of dynamic replacement. The test result shows, by applying dynamic replacement only, the enhancement of intermediate soil is limited. Intermediate soil remains weak and not meet with project performance requirement.

4.2. Dynamic replacement & mixing
CPT shows after dynamic replacement & mixing, intermediate soil has an obvious improvement. Minimum cone tip resistance of 8MPa can be achieved.
Figure 6. Intermediate soil CPT result of dynamic replacement.

Figure 7. Intermediate soil CPT result of dynamic replacement & mixing.

* Top layer after filling with mixed material, further compaction has not been done.
Sample of intermediate soil at 2m depth shows that obvious change occurred on intermediate soil properties. Particularly for particle size distribution, fine content (less than 0.075mm) percentage changes from 88% to 33%.

| Situation | $D_{50}$ (mm) | Liquid Limit | Plasticity Limit | Plasticity Index |
|-----------|---------------|--------------|------------------|-----------------|
| Prior     | 0.047         | 61           | 32               | 29              |
| Post      | 0.910         | 38           | 27               | 11              |

Figure 8. Particle size analysis post dynamic replacement & mixing.

5. Concept of dynamic replacement & mixing

5.1. Principle of dynamic replacement & mixing
The method of dynamic replacement contains 3 stage:
- Filling a layer of Engineering Fill. This will provide a safe working platform also material source for future mixing.
- Dynamic replacement with gravel. Gravel pillar formed in this stage, a) provide support to surface blanketing layer; b) provide path for excessive water pressure dismissing and soft material rising; c) provide material source for future mixing.
- Dynamic mixing. By mixing, the composition of intermediate soil will be permanently changed. Meanwhile the compaction of hammer forces consolidation of intermediate soil.

5.2. Other method of dynamic replacement & mixing
Kwang Wei Lo and Peng Lee Ooi et al. also developed a concept of dynamic replacement & mixing[5]. The principle of this method is after dynamic replacement, using even higher energy punching imported granular material pillar. Such high energy will force pillar material distribute into soft material.
This method is an indirect mixing method compared to method in this paper and requires extra filling material during mixing stage with even higher energy.

6. Conclusion
The dynamic replacement & mixing method stated in this paper, increased a dynamic mixing stage based on traditional dynamic replacement method. Results revealed that this method can effectively improve the composition and properties of intermediate soil. The character of improving composition gives this method a wide suitability of weak material treatment. At the same time, with treated intermediate soil, ground performance is more uniform than traditional dynamic replacement. This will provide a better ground condition for future embedded structure or utilities construction.

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