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COMPACTION OF SAND USING ORDINARY OFF-ROAD VEHICLES

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Summary-This paper examines the possibility of compacting a sandy soil using ordinary off-road vehicles instead of compactors. Laboratory tests showed that a considerable compaction of sand can be achieved if alternative cyclic stresses are applied. Such stresses can be generated if a train of two vehicles is employed for compaction: one vehicle with all wheels driven towed another vehicle having all wheels towed. Compaction was made by making consecutive passages of the train of two vehicles. Procedure of compaction is described and test results are presented. Compacting sand by this method has increased the density up to 92% the value of optimum density obtained by modified compaction test. A considerable amelioration of soil trafficability has also been achieved, this is proved by the experimental drawbar pull-slip relationships measured before and after compaction.

INTRODUCTION

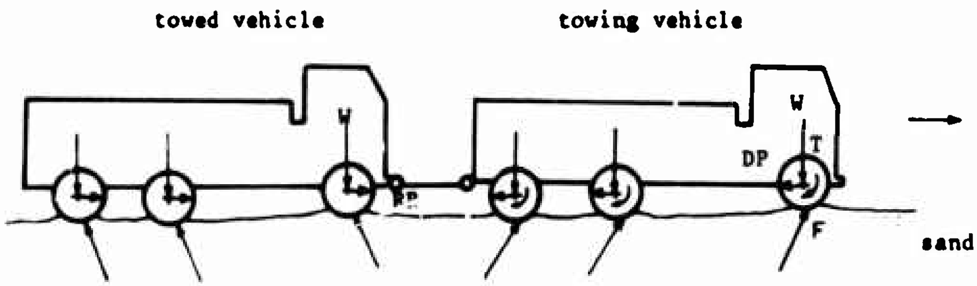
The amelioration of vehicles mobility can be achieved by improving vehicles design and / or by increasing soil traficability by compaction. Compaction is usually achieved by using compactors which need to be transported to the work sites.
If compaction can be done by ordinary offroad vehicles, this would reduce costs and provide an alternative solution to the problem.

Results of triaxial experiments on sand made by FRANCO [1] showed that one can creat considerable volumetric deformations in the soil by applying cycles of alternative stresses.

The intensity of these stresses should be limited so that the induced soil deformation will not be so large, otherwise soil dilatation occurs. In his study, he showed a case where soil dilatation was obtained (volume increased) when sample axial strain was large (± 5%). He also showed another case where soil was compacted (volume decreased) when axial strain was limited to a small value (± 0,75%).

In practice, alternative stresses are applied to the soil if a vehi - cle with all wheels driven towed another vehicle having all wheels towed, this is shown in Fig. 1.

Soil deformation is strongly related to wheels slip, therefore wheels slip should be kept small during compaction. Generally, slip should be lower than 30%[2]. This slip value corresponds in most cases to the maximum drawbar pull developed by the vehicle. Our traction tests carried out before compacting the experimental soil showed that the maximum drawbar pull is delivered at 10% slip. Thus, we tried to keep wheels slip during compaction below this value.



W = part of vehicle weight on the axle
DP = drawbar pull
RR = rolling resistance
F = soil reaction

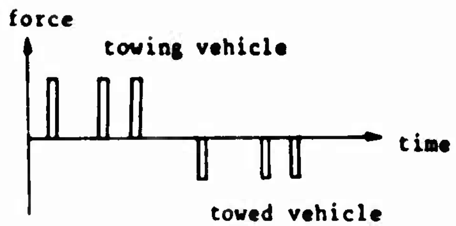


Fig. 1 Forces acting on the soil during compaction.

EXPERIMENTAL SOIL

An uniformly graded sand having a coefficient of uniformity $\frac{D_{60}}{D_{10}} = 2.1$ and a grain size distribution shown in Fig.2 was the experimental soil. Sand bin has a length of 70 m, a width of 7m and a depth of 0,8 m. Moisture content measured before compaction in the layer from 0 to 45 cm of the sand bin was nearly 4%. Laboratory standard and modified compaction tests were carried out, and the dry density-moisture relationships are shown in Fig.3. Compaction curves show that a moisture content of 3 to 5% is unfavourable for compacting such sand. Unfortunately, the existing natural content of 4% was not possible to change because of climate conditions.

Surface of sand in the bin was gently levelled before compaction using a light grader.

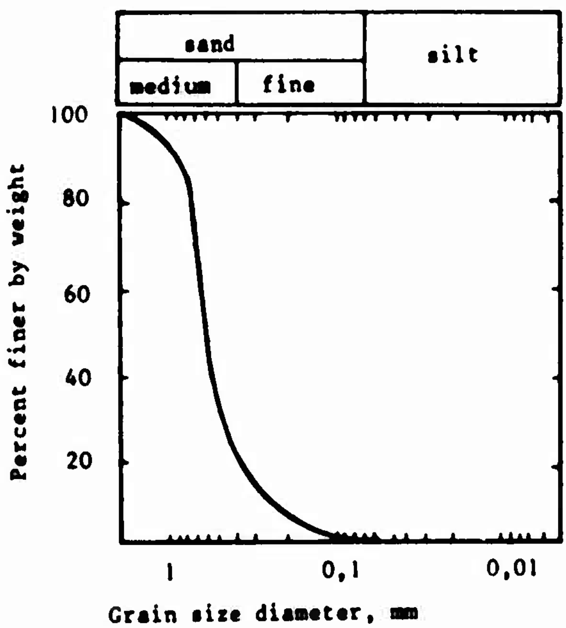


Fig.2 Particle size diameter of experimental soil.

COMPACTION PROCEDURE

Compaction was done by making consecutive passages by the train of two off-road vehicles. The towing vehicle moved with all axles driven and the lowest gear shifted (1^{st} gear in main gear box and low gear in auxiliary geat box). The towed vehicle (connected to the towing vehicle by a steel rope) moved with engine stopped and brakes released.

To increase the resistance on the towing vehicle the top gear in the towed vehicle gear box was shifted and for further increase of resistance a lower gear was engaged.

Increased resistance caused more slip of towing vehicle wheels, thus it was possible to change the degree of slip by shifting different speeds in the towed vehicle gear box. To calculate wheels slip during compaction, the actual distance covered during ten revolutions was measured, and the theoretical distance, which would be covered if wheels purly roll, calculated. Slip value was then determined from the equation:

$$i = \frac{\ell_{th} - \ell_a}{\ell_{th}}$$

where:

i = wheels slip

ℓ_{th} = theoretical distance

ℓ_a = actual distance

First passage was situated 0,5 m from the side wall of soil bin. Followed passages were laterally shifted each by 0,3 to 0,5 m from the former, this is shown in Fig. 4.

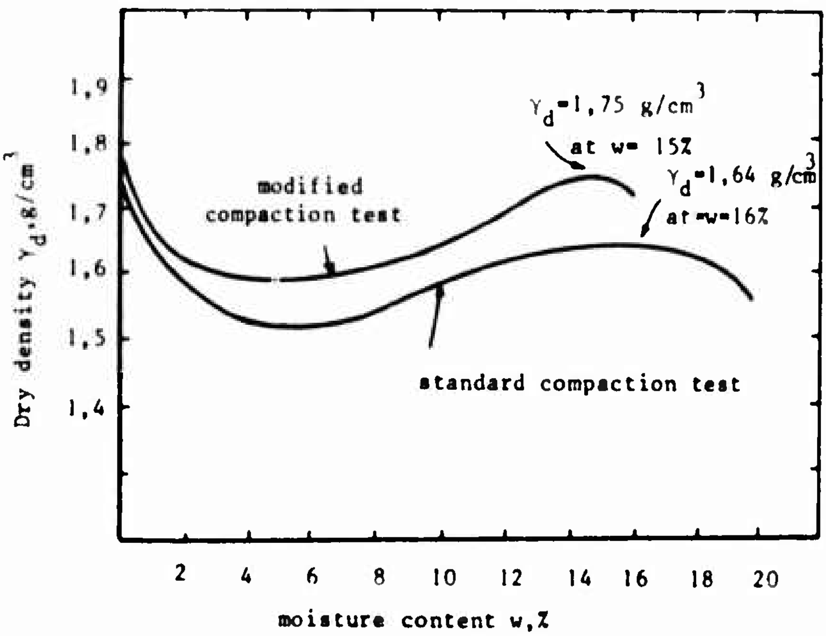


Fig.3 Experimental dry density-moisture relationships.

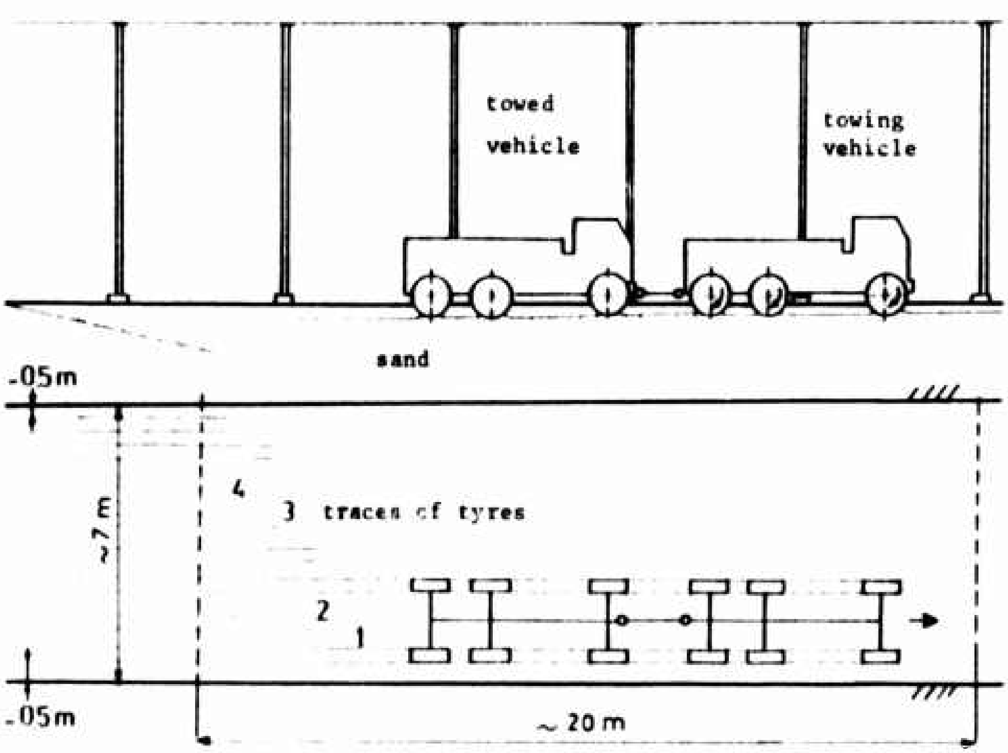


Fig.4 Compaction of the fine sand using the train of two offroad vehicles.

phases		1	2	3	4		
passages		5	4	5	5	3	2
towing vehicle	G	91200					
	p	1,5	2	2,5	3	F:3,7 R:4,0	F:4,0 R:4,5
	i	2,5	3	3,9	4,5	2,7	-
	Tyres: E 22,5 Pilote x M+S4 Michelin						
towed vehicle	G	101200					
	p	1,3	1,7	2,1	1,8		
	Tyres: 12,00-20 Michelin						

G: vehicle weight, Newtons

p: inflation pressure, bars

i: wheel slip, %

F: front wheels R: rear wheels.

Table 1. Description of compaction phases.

MEASURED VALUES

Moisture content was measured before each phase of compaction in ten points of soil bin measuring zone. This zone situated in the middle of soil bin had a length of 20 m and width of 5 m. Moisture content samples were taken at depths of 0,15,30 cm. Places of measuring the moisture content are shown in Fig. 5, and average values were as following:

before compaction $w = 4\%$

before 2nd compaction phase $= 2,5\ \%$

before 3rd compaction phase $= 2,5\ \%$

before 4th compaction phase $= 3,2\ \%$

The in situ density was measured after finishing 2^{nd}, 3^{rd} and 4^{th} compaction phases using γ rays density meter in same points as for moisture content. Before measuring the density, the surface of soil bin was gently levelled. The density meter enabled to have readings of moisture content, bulk and dry densities at depths of 0 to 30 cm. For greater depth (40, 50 cm) the soil surface layers of 10, 20cm thickness were taken off (see Fig.8).

The average of density values in the ten points of same layer was considered as the sand density at that depth.

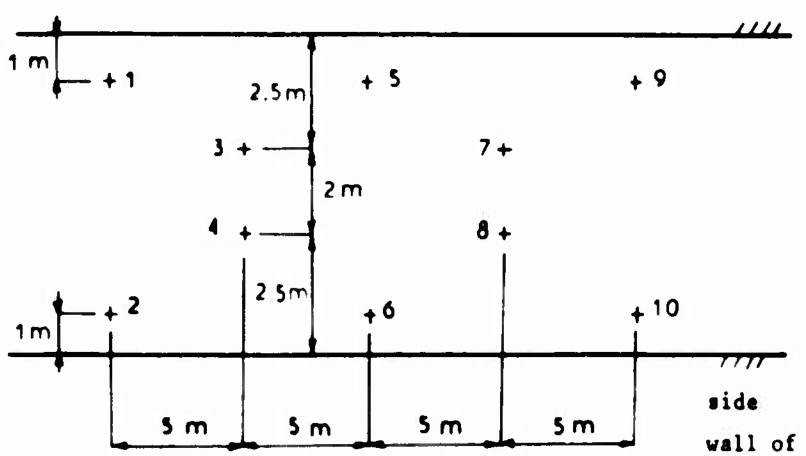


Fig.5 Points of measuring the moisture content and density.

Traction tests were carried out before and after compaction. In these tests the towing vehicle moving in the sand bin pulled a braking vehicle of adjustable braking effort. The pulling force was measured by a force dynamometer. and the speed of travel by a fifth wheel fixed to the towed vehicle. Theoretical speed of vechicle motion was measured by a pulse generator fixed to one of the towing vehicle rear wheels (Fig.9). Instantaneous values of pulling force (drawbar pull), travel and theoretical speeds were continuously recorded on a multichannel recorder, and the drawbar pull-slip relationships were traced.

RESULTS

The in situ dry density-depth relationships (Figs 6,7) are considered as a measure of degree of compaction. Fig.6 shows that after the third compaction phase the sand dry density at a depth of 20 cm increased to 93% of the optimum dry density determined by modified compaction test, at a depth of 30 cm it increased to 95% of the optimum dry density. Fig.7 shows that after the fourth compaction phase the sand dry density at a depth of 30 cm slightly decreased to 92% of the optimum value. But at 50 cm depth, it attained a high value (97% of the optimum).

The drawbar pull-slip relationships (Fig.8) measured beofre and after compaction are considered for evaluating the amelioration of soil trafficability by compaction. Referring to Fig.8, it is seen that the maximum drawbarpull (at 10% slip) increased by 30%, and for lower slip values it increased up to 60 %. Average values of drawbar pull and the corresponding slip are given in table 2.

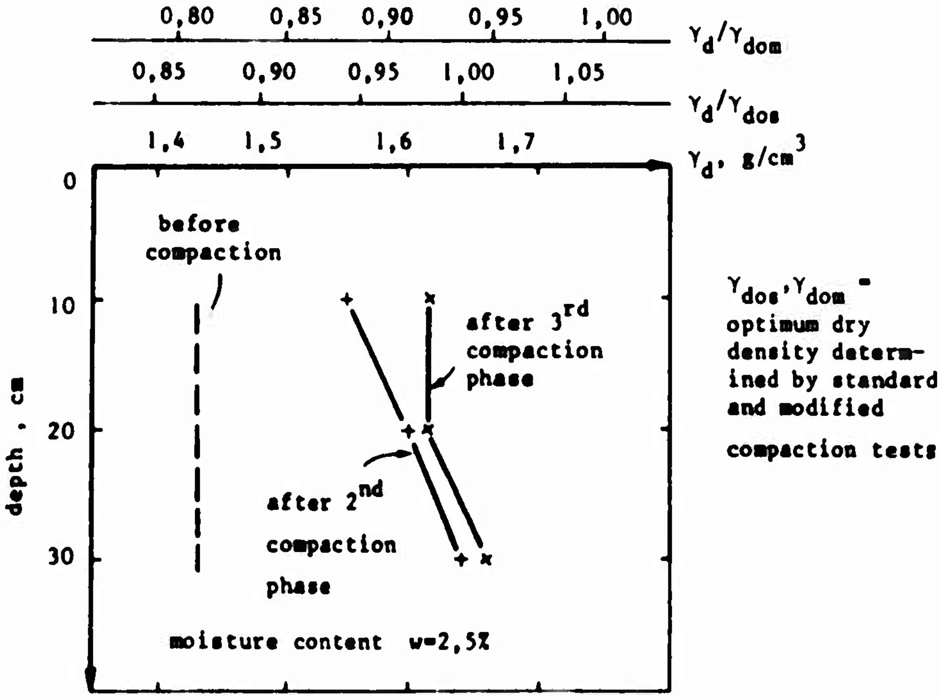


Fig.6 Dry density γ_d vs depth after 2nd and 3rd compaction phases.

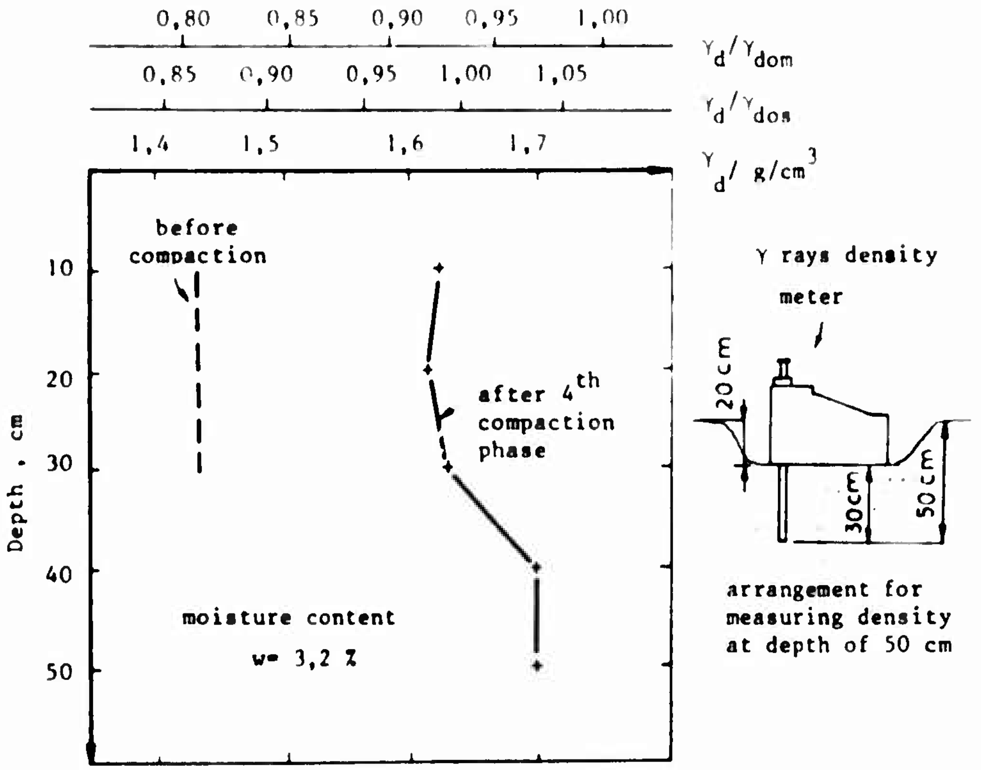


Fig.7 Dry density (γ_d) vs depth after 4th compaction phase

wheel slip%	DP before compaction	DP after compaction	% of increase
3	1360	2185	60,66
5	1625	2235	37,54
7	1785	2300	28,85
10	1830	2385	30,33
15	1825	2300	26,03
20	1690	2155	27,51
30	1560	1835	17,63
40	1410	1700	20,06
60	1136	1370	20,07
80	975	1235	26,67
100	1300	2200	69,23

Table 2 Drawbar pull values before and after compaction.

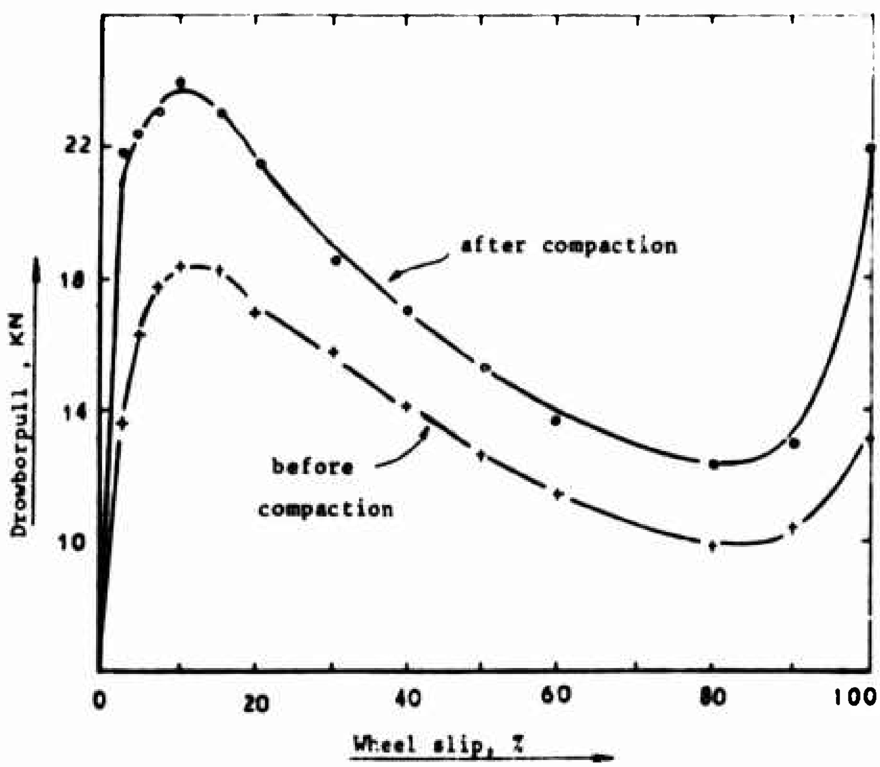


Fig.8 Drawbar pull-slip experimental curves before and after compaction.

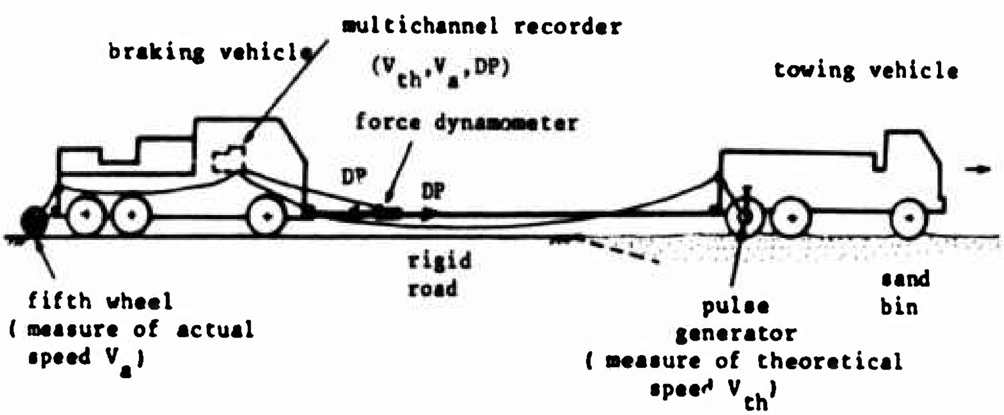


Fig.9 Traction test.

CONCLUSIONS

1. The proposed method for sand compaction in which alternative stresses are applied to the soil using a train of two off-road vehicles proved to be efficient, sand density at a depth of 30 cm increased to 92% of the optimum dry density determined by modified compaction test, and to 95% at 50 cm depth.

2. During compaction of sand, slip of wheels of compactors should be enough lower than the slip corresponding to the maximum drawbar pull determined by traction test. A slip of 5% can be considered as a limit value beyond which soil decompaction occurs.

3. Inflation pressure of vehicle tyres should be successively increased, and a pressure of 3,5 bars can be considered as a limit value. Greater inflation pressure increases the wheels slip and sinkage and leads to soil decompaction

4. A considerable degree of compaction was achieved although the sand was relatively uniform and the moisture content of 3% was unfavourable.

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