

## Effect of moisture content on soil density – compaction relation during soil compacting in the soil bin

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**Abstract:** *Effect of moisture content on soil density – compaction relations during soil compacting in the soil bin.* There are presented results of investigations carried out in the soil bin on fine-grain loamy soil at three moisture contents (8, 12, and 16%). The soil in the bin was compacted by 1-, 2-, 4-, and 8-runs of wheel (with 140, 180 and 220 kPa tire inflation pressures) over the same track under the load 2011, 3600 and 5199 N at speed 0.23, 0.82 and 1.41 m·s<sup>-1</sup>. The investigations aimed at determination of dependence between soil density and its compaction within range of investigations carried out under artificial conditions of the soil bin. The investigations enabled to determine changes in the soil density and compaction in the wide range of variability of measurement conditions. Changes in moisture content of soil subjected to mechanical processing affected soil density more than soil compaction. A statistically significant dependence between soil compaction and density was obtained, with correlation coefficient  $r = 0.843$ .

*Key words:* wheel, soil bin, soil parameters

### INTRODUCTION

Field operations result in changes in the soil state that is characterized by changes in soil consolidation [Buliński and Niemczyk 2009]. The soil density is a basic property that is characteristic for soil consolidation [Świętochowski et al. 1993, Paluszek 2011]. Soil density is an intermediate index of soil compaction and porosity, with respect to their mutual

relations [Reynolds 2008, Buliński and Sergiel 2013]. These relations are considerably shaped by moisture content; it affects the soil susceptibility to action of mechanical forces. Buliński and Powalka [2014] carried out field investigations under natural conditions on the effect of soil consolidation on changes in soil compaction. They obtained a regression dependence between the soil bulk density and soil compaction. The authors found that direct connecting of the soil density and its compaction were difficult and should be reserved with many conditions that limited the application range of worked out model of determination coefficient  $R^2 = 50\%$ . It might indicate that the obtained scatter of measuring points did not allow for better fitting of the model and was connected with the effect of other factors, that were not considered in the obtained dependence. However, the correlation coefficient between these variables ( $r = 0.88$ ) indicates a distinct interdependence of both properties. It was found [Alexandrou and Earl 1998, Szeptycki 2003] that moisture content affected the stress intensity and the range of its propagation.

The carried out investigations aimed at determination of dependence between soil density and compaction under repeatable conditions of the soil bin.

## MATERIAL AND METHODS

The investigations were carried out in the soil bin filled with fine-grain loamy soil, at three moisture contents ( $W$ ): 8, 12 and 16% (percentage by weight). The loosened soil was consolidated by 1-, 2-, 4-, and 8-runs ( $Kr$ ) of tractor front wheel with tire 7.50–20 executed over the same track at three speeds ( $V$ ): 0.23, 0.82 and 1.41  $\text{m}\cdot\text{s}^{-1}$ . The wheel was loaded with force ( $G$ ) in the range 2011–5199 N. Three tire inflation pressures were used ( $P$ ): 140, 180 and 220 kPa. The soil density was measured in each variant with Eijkelkamp probe with containers of volume 100  $\text{cm}^3$ , while soil compaction was measured with cone penetrometer of diameter 20.27 mm and apex angle 30°. The measurements were repeated three times for the layer 0–300 mm. Dry soil density was determined after drying samples at temperature 105°C.

## RESULTS AND DISCUSSION

All results of measurements were analyzed to check, whether the used consolidation variants caused statistically significant diversification of soil density.

Considering values of mean dry soil density in the profile under track at three wheel loadings (Fig. 1), one can find that soil density changed with an increase in moisture content. At the least moisture content (8%) the soil density varied, depending on wheel load, from 1212.3 (at the least load) to 1290.9  $\text{kg}\cdot\text{m}^{-3}$  (at the highest load); in relation to the soil loosened state (with no passages) it corresponded to an increase from 13.6 to 21%. An increase in soil moisture content to 12% caused a change in soil density from 1264.9 to 1375.6  $\text{kg}\cdot\text{m}^{-3}$ , respectively (in relation to soil initial state from 18.6 to 29%). At moisture content 16%, the wheel passages caused the strongest soil compaction. Mean dry soil density at

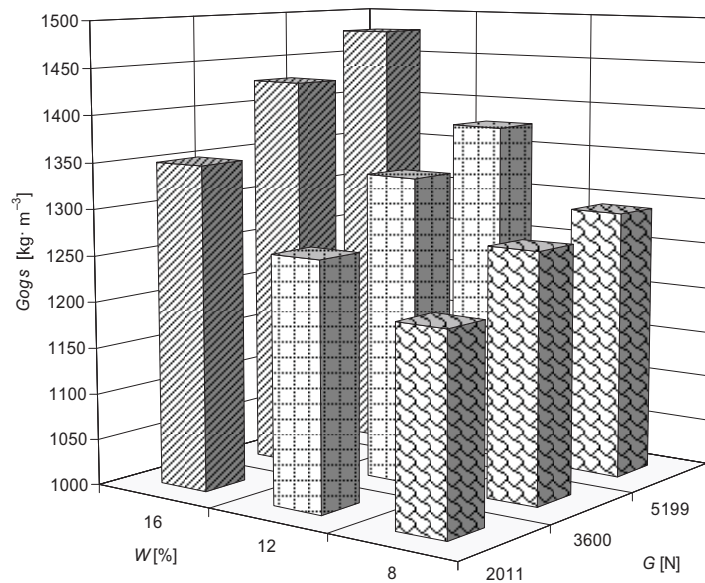


FIGURE 1. Changes in dry soil density ( $Gogs$ ) at various loading ( $G$ ) and moisture content ( $W$ )

wheel load of 2011 N increased to 1349.8  $\text{kg}\cdot\text{m}^{-3}$ , while at the highest load (5199 N) – to 1478.1  $\text{kg}\cdot\text{m}^{-3}$ . When these values are related to not compacted soil, an increase in soil consolidation amounts to 26.5 and 38.6%, respectively. Comparing the extreme value one can find, that an increase in soil moisture content from 8 to 12% caused an increase in soil density (depending on the wheel load) from 5 to 8%; when soil moisture content increase from 12 to 16%, the mean soil density values for particular wheel loadings increased from 6.9 to 7.6%.

Considering mean soil density values obtained after various number of compacting passages (Fig. 2), one can find a systematic increase in soil consolidation with moisture content.

The analysis of measurement results showed that compacting of soil at the least moisture content (8%) increased soil density (in relation to soil initial state

and depending on number of passages) from 140.1  $\text{kg}\cdot\text{m}^{-3}$  (after one passage) to 235.4  $\text{kg}\cdot\text{m}^{-3}$  (after eight passages), i.e. from 13.1 to 22.05%. At moisture content 12%, an increase in soil density for this range of compacting runs' number varied respectively from 191.0 to 314.5  $\text{kg}\cdot\text{m}^{-3}$ , i.e. from 18.2 to 29.5%, while at moisture content 16% an increase in soil density, related to the initial state, varied from 288.9 to 422.3  $\text{kg}\cdot\text{m}^{-3}$  (from 27.9 to 39.6%). It means, that an increase in moisture content by 4% (from 8 to 12%) caused an increase in mean soil density in particular compaction variants by 5.1–7.4%, while the subsequent increase in moisture content by 4% (to 16%) increased compaction on the average by 9.7–10.1%, in relation to respective values obtained at the lower moisture content. An increase in soil moisture content from 8 to 12% caused an increase in mean soil density in particular variants

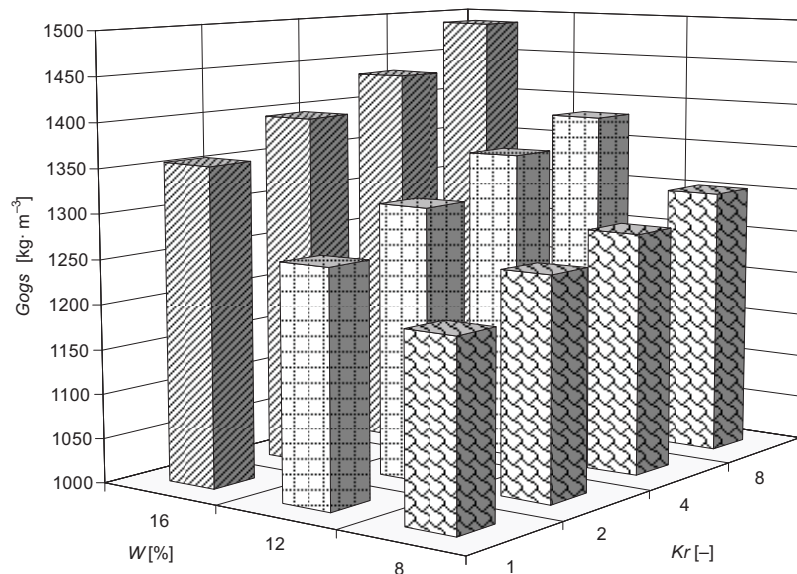


FIGURE 2. Changes in dry soil density ( $G_{ogs}$ ) depending on number of wheel passages ( $Kr$ ) and soil moisture content ( $W$ )

by 5.9–6.9%, while when moisture content was increased to 16%, the soil density increased by 7.3–10.9%, with respect to the values calculated for the lower moisture content.

The effect of moisture content of soil compacted by wheel at various tire inflation pressures on the soil consolidation is presented in Figure 3.

The effect of soil moisture content was also evident in soil density values obtained at particular speeds of wheel passages (Fig. 4). At the lowest moisture content (8%), the mean soil density after wheel passages varied from 1269.4 (at lowest speed) to 1245.3  $\text{kg}\cdot\text{m}^{-3}$  (at highest speed). In relation to the loosened state, the soil density increased by

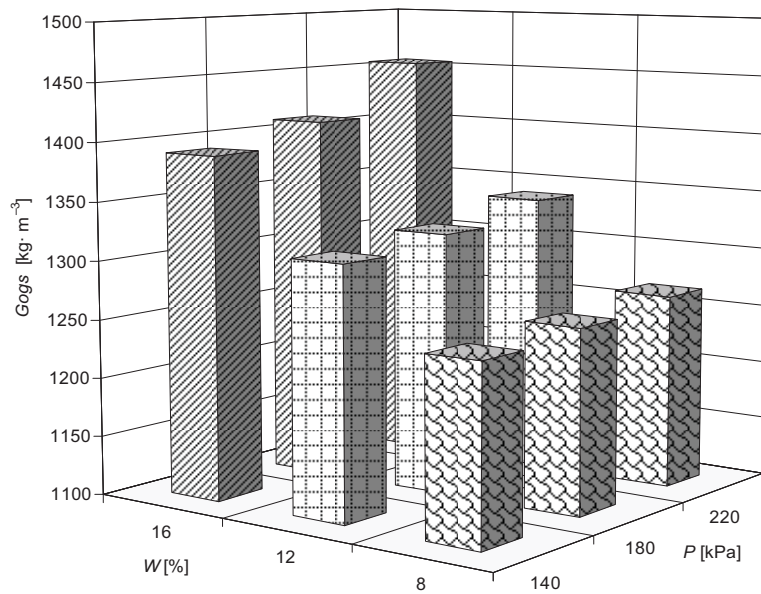


FIGURE 3. Changes in dry soil density (*Gogs*) depending on tire inflation pressure (*P*) and soil moisture content (*W*)

Comparing these measurement results with the values obtained on not compacted soil, one can find that wheel passages at moisture content 8% increased the soil density in the range of 183.2  $\text{kg}\cdot\text{m}^{-3}$  (at the least pressure) to 190.7  $\text{kg}\cdot\text{m}^{-3}$  (at the highest pressure), i.e. from 17.2 to 18.6%. At increase in soil moisture content to 12% resulted in compaction increase by 245.9–257.9  $\text{kg}\cdot\text{m}^{-3}$  (23–25%). After passages at the highest moisture content (16%), the soil density increased by 30.4–36.4%.

16.7% at the highest speed to 19% at the lowest speed. An increase in soil moisture content to 12% caused an increase in soil density (in relation to the initial state) by 22.7–25.4%, while at the highest moisture content (16%) changes in mean soil density in particular variants connected to number of passages varied from 31 to 34.8%, respectively. An increase in moisture content from 8% to 12% caused an increase in soil density after the wheel passage by 6–6.4%, while an increase in moisture content to

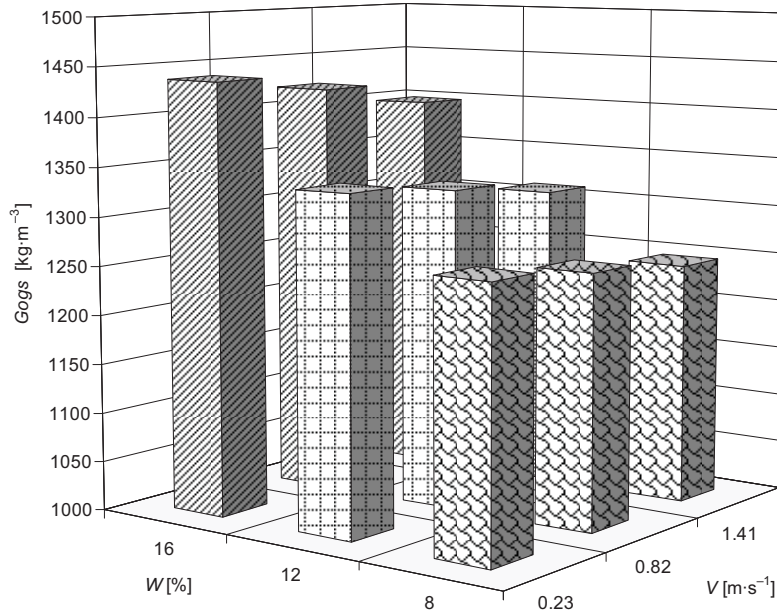


FIGURE 4. Changes in dry soil density (*Gogs*) depending on wheel passage speed (*V*) and soil moisture content (*W*)

16% resulted in an increase in soil density by 8.3–9.4%, when related to the lower moisture content.

All results of measurements on soil consolidation were subjected to statistical analysis. The results of analysis on mean soil density values in particular measuring variants (speed, load, number of passages, tire inflation pressure) at three moisture contents are presented in Figure 5. Results of analysis presented on the diagram on Figure 5 point out that along with an increase in moisture content, the same variants of soil compaction resulted in bigger scatter of measured soil consolidation values. Change in soil moisture content from 8 to 12% caused an increase in mean soil density value from 1257.3 to 1323.8 kg·m<sup>-3</sup>, i.e. by 5.3%, the range of measuring value by about 44% and standard deviation value

by more than 36% ( $\sigma = 69.21$ ). When soil moisture content increased to 16%, the mean dry soil density in particular measuring variants increased to 1418.5 kg·m<sup>-3</sup>, i.e. by 7.2%, while the range of measuring value increase by about 37%; at standard deviation value  $\sigma = 82.55$  it was almost two times bigger in relation to the least moisture content level.

Statistical analysis of all measuring results showed that particular independent variables (load, number of wheel passages over the same track, tire inflation pressure, wheel passage speed and soil moisture content) had a statistically significant effect on soil density, with high level of dependence (Table 1).

The obtained results of measurements gave the ground to find, that the taken compaction variants were correctly diversified, since changes in soil

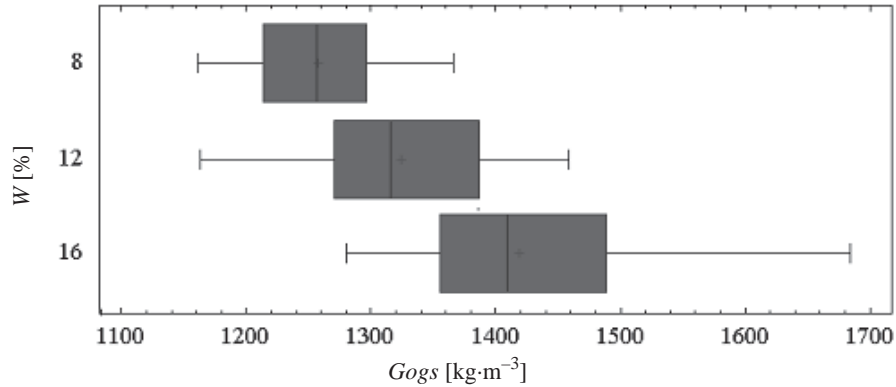
FIGURE 5. Changes in dry soil density ( $G_{ogs}$ ) at three moisture contents ( $W$ )

TABLE 1. Analysis of variance for dry soil density at three soil moisture contents

Source of variability	Sum of squares	Degrees of freedom	Mean square	$F_{emp}$	P
Load, $G$	619 134.0	2	309 567.0	610.73 <sup>a</sup>	0.0000
Number of passages, $Kr$	615 593.0	3	205 198.0	404.83 <sup>a</sup>	0.0000
Tire inflation pressure, $P$	71 902.0	2	35 951.0	70.93 <sup>a</sup>	0.0000
Ground speed, $V$	51 861.8	2	25 930.9	51.16 <sup>a</sup>	0.0000
Moisture content, $W$	1.41778E6	2	708 889.0	1 398.54 <sup>a</sup>	0.0000
Residue	158 146.0	312	506.877	×	×
Total	2.93441E6	323	×	×	×

<sup>a</sup>Effect of factor significant at  $\alpha = 0.05$ .

consolidation for particular level of independent variables were statistically significant.

Together with the measurements on soil density, the soil compaction was measured under the same consolidation variants. The results of soil compaction measurements showed a considerably higher scatter of values (Fig. 6). An increase in soil moisture content from 8 to 12% caused an increase in mean soil compaction value from 598.03 to 664.83 kPa, i.e. by more than 11%. At the same time, this moisture content change resulted in

above 33%-increase in the range of measured values, with standard deviation of  $\sigma = 285.9$ . This value was equal to almost 43% of mean soil compaction obtained at moisture content of 12%. An increase in soil moisture content to 16% resulted in an increase in mean compaction to 912.9 kPa, i.e. by more than 37%, with standard deviation  $\sigma = 377.4$ ; this pointed out at the increased scatter of measured values.

In order to check the effect of particular factors (wheel load, tire inflation pressure, number of passages, ground speed and soil moisture content), all the

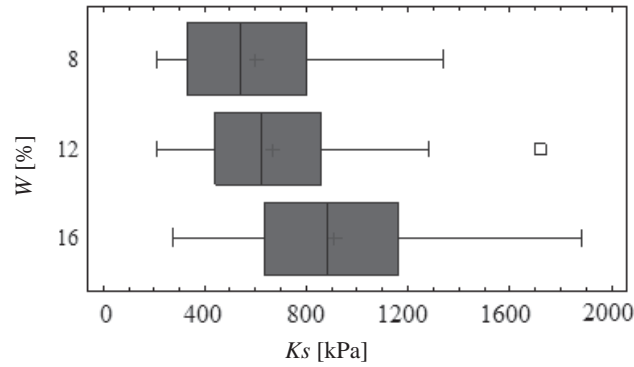


FIGURE 6. Changes of soil compaction ( $K_s$ ) at three moisture contents ( $W$ )

measurement results were subjected to statistical analysis; its results are presented in Table 2.

The obtained values of significance levels for particular independent factors

soil particles. Under conditions of soil bin, as well as in cultivated soils, where effect of natural binding forces is decreased as a result of machines and implements operation, compaction affects considerably

TABLE 2. Analysis of variance for soil compaction at three soil moisture contents

Source of variability	Sum of squares	Degrees of freedom	Mean square	$F_{emp}$	P
Load, $G$	6.78929E6	2	3.39465E6	322.84 <sup>a</sup>	0.0000
Number of passages, $Kr$	2.11884E7	3	7.06279E6	671.70 <sup>a</sup>	0.0000
Tire inflation pressure, $P$	1.00832E6	2	504 162.0	47.95 <sup>a</sup>	0.0000
Ground speed, $V$	708 353.0	2	354 177.0	33.68 <sup>a</sup>	0.0000
Moisture content, $W$	5.94472E6	2	2.97236E6	282.68 <sup>a</sup>	0.0000
Residue	3.28064E6	312	10 514.9	×	×
Total	3.89197E7	323	×	×	×

<sup>a</sup>Effect of factor significant at  $\alpha = 0.05$ .

allow for rejection of the statistical null hypothesis on equality of mean value in the compared groups. On that ground one can find, that independent variables in the range of assumed levels of values significantly affect the soil compaction.

The soil compaction is a characteristic feature for binding forces of particular

the layer “coherence” that causes unnatural, tighter arrangement of soil particles and an increase in the layer’s density and compaction. To check connection of these two features under assumed conditions of external impacts, all measuring results of soil density and compaction were subjected to statistical analysis.

The results of analysis (Table 3) showed, that between density and compaction variables a highly significant dependence occurred in the assumed range of measurements, at confidence level 99%.

and Powalka [2014]), it still does not provide a satisfactory level of relation for practical utilization. Especially, it concerns the upper level of soil consolidation (Fig. 7), of considerable scatter of measuring values. This scatter can

TABLE 3. Regression analysis for soil compaction – density dependence

Dependent variable: $K_s$ , independent variable: $G_{ogs}$				
Parameter	Estimate	Standard Error	T Statistic	P-value
Intercept	-29 156.3	1 063.45	-27.4168	0.0000
Slope	4 154.33	147.84	28.1002	0.0000

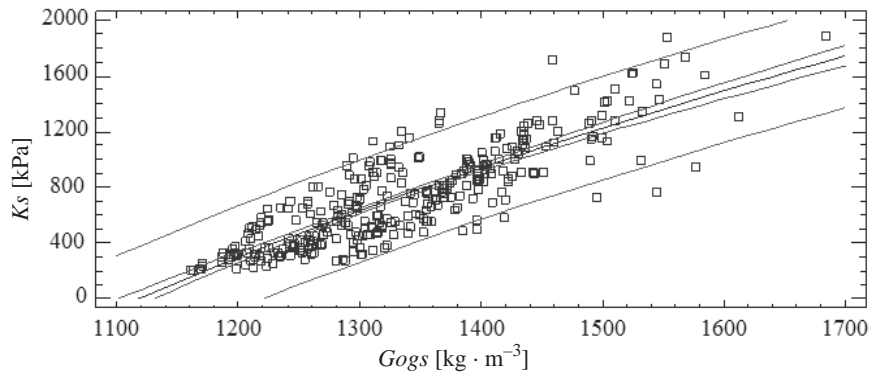


FIGURE 7. Dependence between soil density and compaction for assumed conditions of measurements

This dependence can be presented in the form of diagram (Fig. 7) and described with equation:

$$K_s = 4154.33 \cdot \ln(G_{ogs}) - 29156.3$$

where:

$$R^2 = 71.03\%;$$

$$r = 0.843;$$

$$SEE = 187.1.$$

In spite of a distinct and fairly strong connection between both features, the presented logarithmic regression model of fitting  $R^2 = 71.03\%$  (although of better fitting than that presented by Buliński

be connected with a “lubricating” effect of soil water that result in a decrease in the cone resistance, especially at higher moisture contents.

## CONCLUSIONS

1. The carried out investigations enabled to determine changes in soil density and compaction in the wide range of measurement conditions variability, characterized by soil moisture content, wheel load, number and speed of passages over the same track.



2. Changes in moisture content of soil subjected to mechanical impacts affected stronger the soil density, then the soil compaction.
3. Between the soil density and compaction under conditions of carried out measurements there was obtained a statistically significant dependence of correlation coefficient  $r = 0.843$ .

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- Streszczenie:** *Wpływ wilgotności na relację gęstość – zwięzłość gleby podczas jej zagęszczania w kanale glebowym. Przeprowadzone badania miały na celu określenie zależności regresyjnej wiążącej zwięzłość gleby z jej gęstością zmienianą w sposób kontrolowany wielokrotnymi (1-, 2-, 4- i 8-krotnymi) przejazdami koła przy trzech poziomach obciążenia (2011, 3600 i 5199 N), trzech poziomach ciśnienia w oponie (140, 180 i 220 kPa) i trzech prędkościach (0,23, 0,82 i 1,41 m·s<sup>-1</sup>). Na podstawie otrzymanych wartości pomiarowych gęstości i zwięzłości gleby można stwierdzić, że wraz ze wzrostem wilgotności takie same warianty ugniecenia gleby prowadziły do większego rozproszenia mierzonych wartości zagęszczenia gleby. Analiza statystyczna całości wyników pomiarowych wykazała istotny wpływ wszystkich czynników (prędkości, ciśnienia, obciążenia, liczby przejazdów) na gęstość gleby. Otrzymane równanie regresyjne opisujące związek gęstość – zwięzłość gleby wskazuje na dobre dopasowanie do wartości pomiarowych ( $R^2 = 71,03\%$ ) i dość dobrą zależność międzycechową. Jednakże, rozrzut wartości zwłaszcza w górnym poziomie zagęszczeń nie zapewnia satysfakcjonującego poziomu relacji dla praktycznego wykorzystania modelu w całym zakresie warunków przyjętych w badaniach.*

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