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Construction and Building Materials 19 (2005) 319–325
Construction and Building MATERIALS
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Effects of formwork surface materials on concrete lateral pressure

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Received 5 November 2002; received in revised form 2 July 2004; accepted 20 July 2004
Available online 12 September 2004

Abstract

In this study, the effect of formwork surface materials on the concrete lateral pressure was investigated. Seven wall formworks were constructed. Populus nigra timber, pinus silvestris timber, plywood and steel sheet were used as surface materials for these formworks. One of two formwork, which had the same surface material, was watered except for the steel formwork before placing the concrete. Concrete was placed into the formworks and the lateral pressures of concrete on formworks surface were measured by a strain measurement system. As comparison the limiting value of concrete lateral pressure was calculated by ACI-347 equation.

It was concluded that, watering the surface of wood formworks increased lateral pressure of concrete on the formworks. Lateral pressure of steel formwork was equal to limiting value of ACI-347 and larger than lateral pressure of populus nigra, pinus silvestris, and plywood formworks. The lateral pressure of pinus silvestris formwork was some less than 3.3%, 7.2%, 21%, respectively, lateral pressure of populus nigra, plywood, and steel formwork".

Keywords: Concrete; Formwork and lateral pressure

1. Introduction

Formwork must support all loads (dead, imposed, environmental and other loads), which may be applied until these loads can be carried by the concrete structure itself. Determining the lateral pressure on vertical formwork surfaces and the influencing variables of pressure has been an important issue [1,2]. In cast-in-place reinforced concrete building construction, formwork expenses can be as high as 50% of the total cost of the reinforced concrete structure [3].

In conventional construction, wood formwork surface are sometimes watered before placing concrete. This causes some changes in water/cement ratio of the concrete, on friction resistance between formwork and concrete surfaces, and the water absorption by formwork surfaces [4].

Generally, in normal construction practice, concrete is placed in 1 m layer and compacted by using poker-type vibrators, which are immersed into only the top 1 m of the concrete. Fig. 1 represents the placing of a wall. In this figure, concrete is placed to a depth of 1, 2 and 3 m, respectively. In each case, the vibrator is immersed 1 m into the concrete. In the first case, the concrete is completely fluidised and the lateral pressure is hydrostatic (Fig. 1(a)). In the second case, the effect of the vibrator will extend below the vibrator and the 2 m depth of concrete will be fluidised, giving hydrostatic pressure (Fig. 1(b)). In the last case, the lower concretes develop significant shear strength, settling vertically under load and developing friction between the concrete and the formwork surface (Fig. 1(c)) [5].

Over the years, various factors, which affect lateral pressure of fresh concrete on vertical forms, have been investigated. These factors have included rate of placing

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doi:10.1016/j.conbuildmat.2004.07.007

Nomenclature

C_1	coefficient depending on the size and shape of formwork
C_2	coefficient depending on the constituent materials of concrete
D	density of concrete (kg/m^3)
H	vertical formwork height (m)
h	height of fresh concrete above point considered (m)
K	temperature coefficient of taken as $[36/(T+16)]^2$
l	length of formwork (m)
P	lateral pressure of concrete (kPa)
P_{max}	limiting value of lateral pressure (kPa)
R	rate of placement (m/h)
P_{s1}	lateral pressure for first strain gauge plate of a formwork (kPa)
P_{s2}	lateral pressure for second strain gauge plate of a formwork (kPa)
T_c	temperature of concrete in the forms (°C)

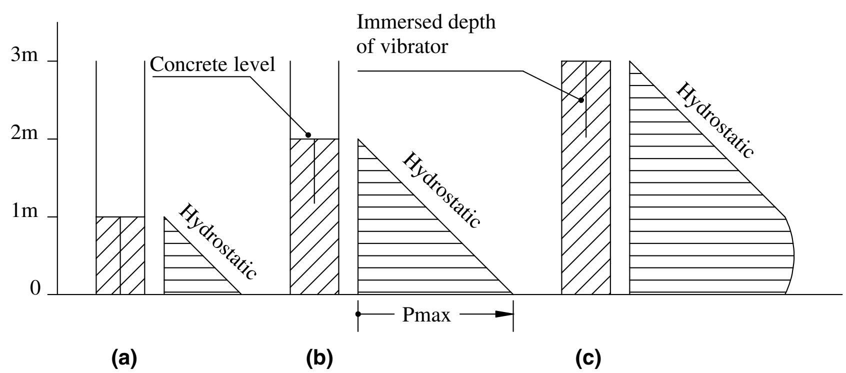

Fig. 1. Development of lateral pressure envelope.

the concrete, temperature of the concrete, proportion of the concrete mix, consistency of the concrete, consolidation method of the concrete, impact during placing, size and shape of the formwork, amount and distribution of the reinforcing steel, unit weight of the concrete, height of the concrete, ambient temperature, smoothness and permeability of the formwork, pore water pressure and type of cement [6,7].

As the result of recent studies, empirical equations have been proposed to calculate the lateral pressure of fresh concrete against formwork surfaces. Some of the equations, which are generally used, are given below.

ACI committee 347 proposes that the equation, which is given below, can be used to calculate lateral pressure of fresh concrete on vertical formwork surface. In the equation, height of fresh concrete (h), rate of concrete placement (R) and concrete temperature (T_c) at placing are the independent variables [8].

For walls with (R < 2 m/h):

$$P_{max} = 7.2 + (785R)/(T_c + 17.8)\ (\text{kPa}), \quad (1a)$$

$$P_{max} \text{ not to exceed } 23.5h \text{ or } 95.8\ (\text{kPa}). \quad (1b)$$

CIRIA proposes the lateral pressure equation given below. This equation involves consideration of formwork size and shape; constituent materials of the concrete, concrete density, formwork height, vertical placement height of concrete, rate of concrete placement and concrete temperature at placing [9]:

$$P_{max} = D\left(C_1\sqrt{R} + C_2K\sqrt{H - C_1\sqrt{R}}\right)\ (\text{kPa}), \quad (2a)$$

$$P_{max}\text{: } D.H\ (\text{kPa}). \quad (2b)$$

It is recommended that the lower lateral pressure value calculated using Eqs. (2a) and (2b) be used as maximum lateral pressure.

DIN 18218 presents a series of equations to calculate the limiting lateral pressures of internally vibrated concrete of various mobilities at a concrete temperature of 15 °C [10]. Rate of concrete placement and the concrete temperature at placing are the essential factors to calculate lateral pressure:

$$P_{max} = 21 + 5R\ (\text{kPa}) \text{ for stiff mix}, \quad (3a)$$

$$P_{max} = 19 + 10R\ (\text{kPa}) \text{ for soft mix}, \quad (3b)$$

$$P_{max} = 18 + 14R\ (\text{kPa}) \text{ for fluid mix}. \quad (3c)$$

To adjust for concrete temperatures other than 15 °C the limiting pressure must be decreased by 3% for every degree above 15 °C and increased by 3% for every degree below 15 °C.

Density of concrete, vibration, size of member being formed, temperature of concrete, rate of concrete placement, slump of concrete, superplasticizer, fly ash, slag cement, admixture and pumped concrete can be considered significant to the lateral pressure problem [5,11].

However, it is seen that there are no variables, which relate to the formwork surface material (such as timber, plywood, steel or any other) in the above-mentioned equations. In fact, when concrete is placed in formworks that have different surface materials, the lateral pressure of concrete is expected to change.

The aim of this study is to search the effects of some formwork surface materials on the lateral pressure of fresh concrete.

2. Experimental details

2.1. Materials

Populus nigra timber, pinus silvestris timber, beech plywood and steel sheet were used to construct formwork surfaces, in treatment of formwork surface, mould oil was used.

Populus nigra timber had 12.10% humidity, 397 kg/m^3 density and 5.09 mm annual ring thickness. Pinus silvestris timber had 12% humidity, 485 kg/m^3 density, and 2.75 mm annual ring thickness. Beech Plywood had 10.90% humidity and 672 kg/m^3 density. Steel sheet was chosen according to EN 10111 [12].

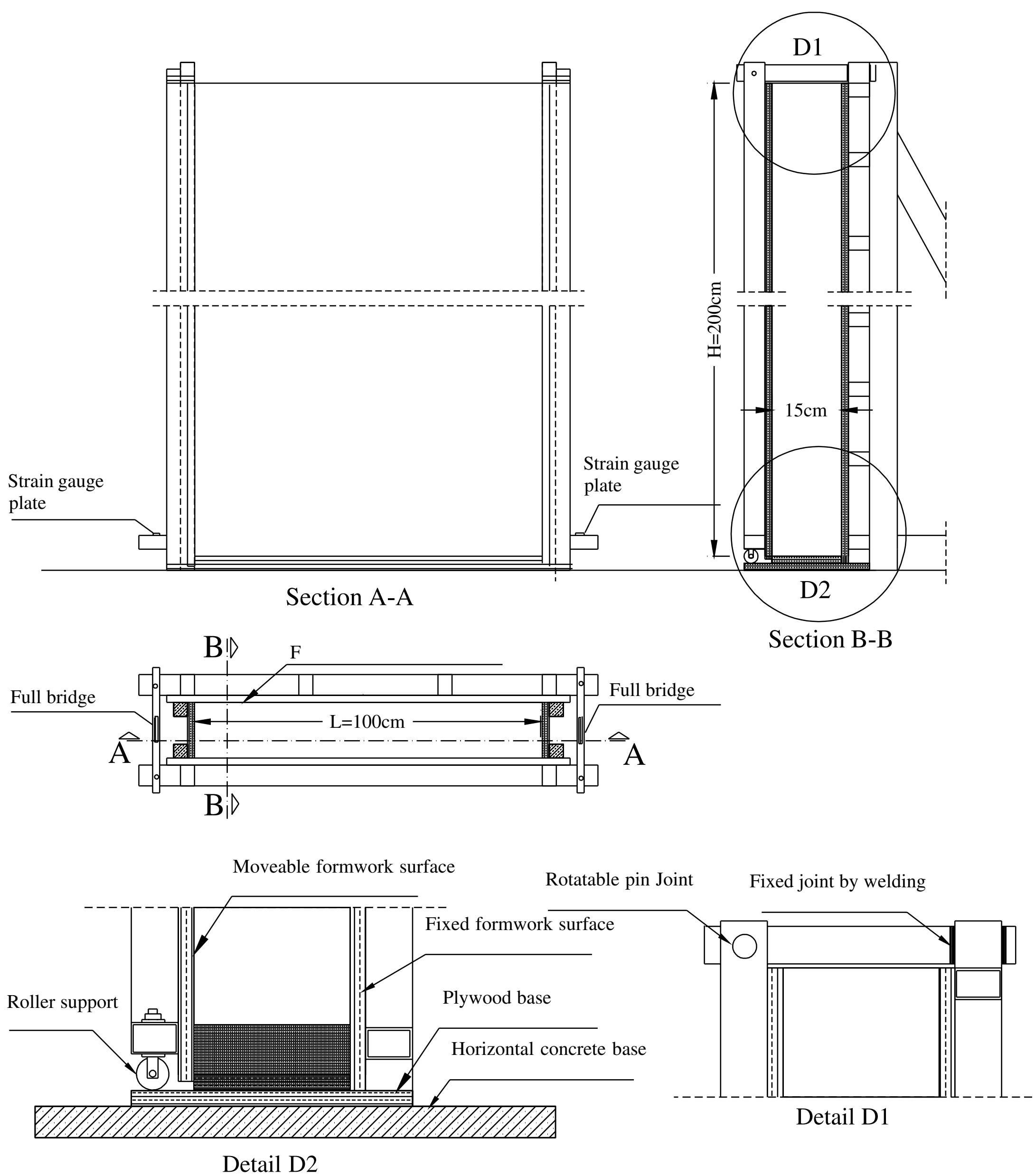

Fig. 2. Project of formwork.

The concrete mix was made from Type I cement, natural sand (0–3 mm), crushed sand (3–7 mm) and crushed coarse aggregate (7–15 mm) using mix proportions of 1:1:1.4:1.75 (by weight) with a cement content of 400 kg/m^3 and water cement ratio of 0.48 [13], and no pozzolans or admixtures. The concrete was batched in a concrete plant. A concrete pump was used for placement and the concrete was sampled at the discharge line for slump and density test. Slump and density of the concrete were measured as 10 cm and 2400 kg/m^3, respectively.

2.2. Preparation of formworks

In order to measure concrete lateral pressure, seven wall form with the dimensions of 100 cm length; 200 cm height and 15 cm thick were constructed. Surfaces of two forms were populus nigra timber, two were pinus silvestris timber, two were plywood and the last one was steel sheet.

One surface of each form was fixed by welding to a supporting structure to make it stable, during the concrete placement process. The other surface of the formwork was mounted by a pin at its upper point to allow it to rotate. The bottom part of this rotatable surface sat on ball bearings in order to minimize friction, as shown in Fig. 2.

Surfaces of all seven formworks were treated with mould oil. Then, one of each pair of formworks, which had the same surface material (such as populus nigra timber, pinus silvestris timber and plywood), was watered before concrete was placed.

2.3. Lateral pressure experiment

To measure lateral pressure exerted by fresh concrete against the form surfaces, two strain gauge plates were designed for each test (as seen in Fig. 3(b)). Full bridge (Wheatstone bridge) with gauges 10 mm long, −10% transverse sensitivity, 120 ± 03 Ω resistance, were set up on every strain gauge plate as seen in Fig. 3(c) [14]. Strain gauge plates were calibrated by applying known forces. For each strain gauge plate, a regression formula (given in Appendix A) was developed between the applied forces and corresponding strain values. Strain gauge plates were mounted at each bottom side of formworks, as seen in Fig. 2. The full bridge circuits were connected to computing data logger via a switching box as it is seen in Fig. 3(a).

All wall forms were cast at the same time. The concrete was placed into wall formworks as two layers by pump. Each layer was compacted by a poker vibrator at three points. Rate of concrete placement was 1 m/h. Temperature of the air and the concrete were measured within 1 and 3 h intervals during concrete placing and measurement of lateral pressure. Measured temperatures can be seen in Table 1.

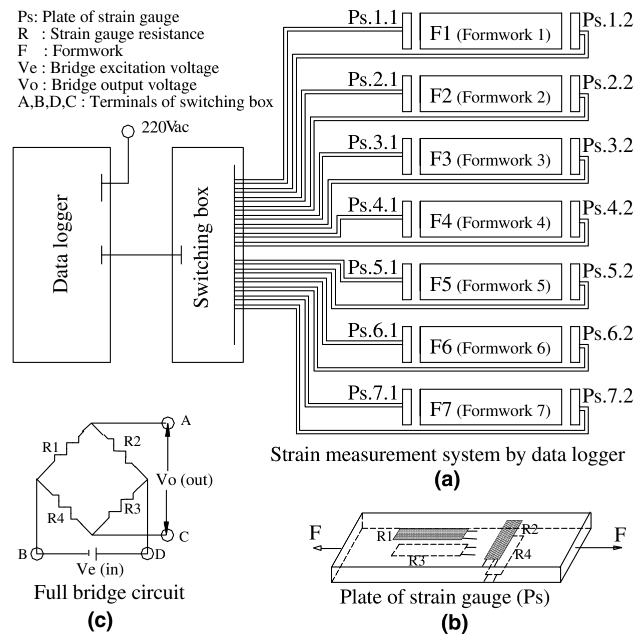

Fig. 3. Design of strain gauge plate and strain measurement system by computer based data logger.

Table 1
Measured temperature during lateral pressure experiment

Measuring conditions	Temperature (°C) Concrete	Air
During concrete placement	22	25
1 h Later after concrete placement	28	23
3 h Later after concrete placement	32	18
6 h Later after concrete placement	32	18

Immediately after completion of concrete placement, strain measurements were started. A total of 252 strains value were measured for 464 min and recorded on the data logger. These measurements were taken from 14 strain gauge plates (for 7 forms at the same time). Measurements were taken for 10 min at 6 s intervals, for 45 min at 30 s intervals, for 65 min at 4 min intervals and for 344 min at 8 min intervals. However changes between measurements were evaluated and the changes in 8 min intervals were seen significant. Therefore, data analysis was performed on 58 strain values, which were measured for 464 min by 8 min intervals.

In this experimental study, the concrete placing conditions are same as the conditions for Fig. 1(b). As can be observed in Fig. 1(b), the lateral pressure envelope is triangular. So, maximum lateral pressure is expected to occur at the bottom of the formwork (on the strain gauge plates).

Assuming the lateral pressure distribution to be triangular the following formula was used in calculating lateral pressure on the form surface:

$$P = \frac{P_{s1} + P_{s2}}{Hl} \text{ (kPa)}. \quad (4)$$

By considering concrete specifications and concrete placing conditions, the limiting values of concrete lateral pressure (P_{max}) were calculated by using the equations proposed by ACI-347, CIRIA, and DIN-18218. In discussion of experimental results, these limiting values were used as reference to compare to the lateral pressure value of formworks. The data of lateral pressure experiment were analysed by Duncan test and graphics. When comparing lateral pressures with the limiting values of ACI-347, CIRIA, and DIN-18218, measured maximum lateral pressures in the 464th minute were used. When comparing measured lateral pressures of seven formworks with each other by Duncan test, 58 values, which were recorded during 464 min, of each formwork were used. $\alpha = 0.005$ were chosen as degree of significance.

3. Results and discussions

Table 2 summarizes the lateral pressure values measured at concrete lateral pressure experiment for 464 min and indicates the limiting values (P_{max}), which are calculated by equation of ACI-347, CIRIA, and DIN-18218. Table 3 shows the results of Duncan tests and the ordering of formworks according to the values of their lateral pressure.

Lateral pressure limiting values: 26.97 kPa for ACI-347, 30.98 kPa for CIRIA, and 29.00 kPa for DIN-18218 are calculated. Limiting value of ACI-347 is the smallest lateral pressure value among the lateral pressure values calculated.

According to measured maximum lateral pressures of formworks in the 464th minute, maximum lateral pressure values are: 23.47 kPa for F1, 21.88 kPa for F2, 25.11 kPa for F3, 21.15 kPa for F4, 25.9 kPa for F5, 22.81 kPa for F6, and 26.97 kPa for F7. The largest lateral pressure was 26.97 kPa in test F7 (steel sheet) formwork and this lateral pressure was approximately equal to the limiting value of ACI-347. The smallest lateral pressure was 21.15 kPa in test F4 (pinus silvestris) formwork (Table 2).

The recorded lateral pressure of all formworks increased continuously during 464 min. However increase rates showed differences according to surface materials of formworks as seen in Fig. 4. It is thought that, this increase in lateral pressures was caused by concrete swelling during setting time. In addition to this, water absorption of wood formwork surfaces caused some swelling in formwork surfaces. Although concrete swelling was the same, swelling of the formwork surfaces was not same because of the differences in surface materials of formworks. Because of this, the increases in the rate of lateral pressures were different [15]. Watering formwork surfaces increased lateral pressures 0.08% in F1–F2 (populus nigra) formworks 15% in F3–F4 (pinus silvestris) formworks, and 12% in F5–F6 (plywood) formworks.

It was seen that, there was a significant difference between the lateral pressure averages of all formworks (F1, F2, F3, F4, F5, F6, F7). In the wood (populus nigra, pinus silvestrist, and plywood) formworks, maximum lateral pressures of F2, F4, and F6 formworks were smaller than maximum lateral pressures of F1, F3, and F5 formworks (Table 3). Because F1, F3, F5 formworks were watered.

According to measured maximum lateral pressures of formworks, F1 (populus nigra, watered) formwork had ≈11%, F2 (populus nigra) 18%, F3 (pinus silvestris, watered) 6.8%, F4 (pinus silvestris) 21%, F5 (plywood, watered) 3.8%, and F6 (plywood) 15% less lateral pressure than lateral pressure of F7 (steel) formwork and limiting value of ACI-347. In the non-watered formworks, F4 (pinus silvestris) formwork had ≈3.3% less lateral pres-

Table 2
Value of lateral pressure of concrete on formwork surface (kPa)

Formwork code and surface process	Lateral pressure (kPa)		
	Mean	Minimum	Maximum
F1 populus nigra (watered)	22.85	21.77	23.74
F2 populus nigra	20.93	19.94	21.88
F3 pinus silvestris (watered)	23.68	21.39	25.11
F4 pinus silvestris	19.91	18.01	21.15
F5 plywood (watered)	24.55	22.47	25.96
F6 plywood	21.48	19.22	22.81
F7 steel	26.19	24.70	26.97
Limiting value of ACI 347			26.92
Limiting value of CIRIA			30.98
Limiting value of DIN-18218			30.98

Table 3
Results of Duncan tests of lateral pressure data

Formwork codes and comparison of differences								Formwork	
Code	F1	F2	F3	F4	F5	F6	F7	Code	Pressure (kPa)
F1		S*	S*	S*	S*	S*	S*	F7	26.19
F2	S*		S*	S*	S*	S*	S*	F5	24.55
F3	S*	S*		S*	S*	S*	S*	F3	23.68
F4	S*	S*	S*		S*	S*	S*	F1	22.85
F5	S*	S*	S*	S*		S*	S*	F6	21.48
F6	S*	S*	S*	S*	S*		S*	F2	20.93
F7	S*	S*	S*	S*	S*	S*		F4	19.91

S*: the mean difference is significant at the 0.05 levels.

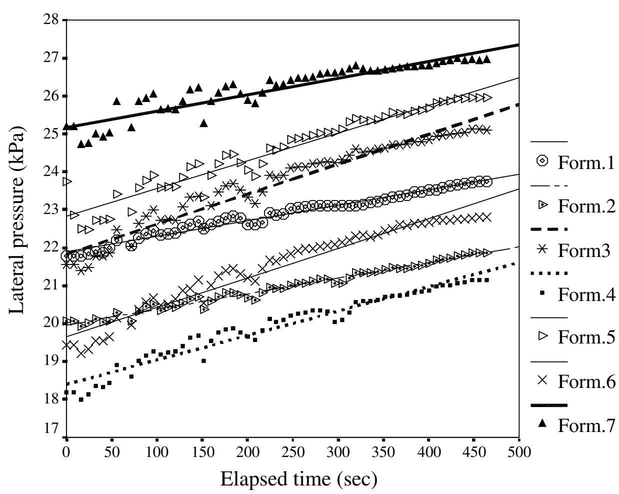

Fig. 4. Variation of lateral pressure with elapsed time.

sure than lateral pressure of F2 (populus nigra) formwork and 7.2% less lateral pressure than lateral pressure of F6 (plywood) formwork.

4. Conclusions

It was seen that, there was significant differences between lateral pressures of all seven formworks. ACI-347 has the smallest value among the limiting values and this value is approximately equal to the maximum lateral pressure value of steel formwork. Lateral pressure of steel formwork was equal to limiting value of ACI-347 and larger than lateral pressure of populus nigra, pinus silvestris, and plywood formworks. Watering the surface of wood formworks increased lateral pressure of concrete on the formworks. Lateral pressure of pinus silvestris formwork was the smallest.

In the non-watered form, it was observed that the lateral pressure of pinus silvestris formwork was some:

- 3.3% less than lateral pressure of populus nigra formwork;
- 7.2% less than lateral pressure of plywood formwork;
- 21% less than lateral pressure of steel formwork and ACI-347

Appendix A. Regression formulas of strain gauge plats

Strain gauge plate code	Value measured (μV)				Regression formula
	10	30	60	100 kg	
SP.1.1	18	52	102	167	$Y = -164.0549 + 592.1557X$
SP.1.2	17	51	102	169	$Y = -164.0471 + 592.1569X$
SP.2.1	17	52	103	171	$Y = -6381.4 + 631.4888X$
SP.2.2	18	52	104	172	$Y = -485.28288 + 583.8906X$
SP.3.1	19	54	105	174	$Y = -1166.1 + 581.6748X$
SP.3.2	17	51	101	168	$Y = -256.5183 + 596.7687X$
SP.4.1	17	51	101	168	$Y = -256.5183 + 596.7687X$
SP.4.2	18	53	105	174	$Y = -492.6445 + 577.3017X$
SP.5.1	17	52	103	171	$Y = -174.0495 + 585.3679X$
SP.5.2	16	49	98	163	$Y = -256.5132 + 596.7687X$
SP.6.1	18	52	102	168	$Y = -1033.9 + 600.6493X$
SP.6.2	19	55	108	177	$Y = -1145.8 + 570.1059X$
SP.7.1	19	54	106	173	$Y = -1421.7 + 584.5789X$
SP.7.2	16	48	97	163	$Y = 462.9674 + 611.8306X$

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