Working Paper No. **HDH-15-08-rev1e**
(15th HDH meeting, 24 to 25 October 2013)

Checking the Influence of WHVC Compensation Method on Emission Test Results

<Background of the Verification>

- The 11th Heavy Duty Hybrids Informal Group Meeting (HDH-IG) mentioned basing the test cycle in HILS on WHVC. At the 7th HDH-IG meeting, however, it was reported that system output is different between WHTC, the test cycle for conventional vehicles, and WHVC.
- To ensure the consistency of test cycles between conventional vehicles and HEVs, HDH-IG finds it necessary at least to ensure the consistency of positive work between WHTC and WHVC.
- To ensure the consistency of positive work, Japan and Europe propose providing slope or changing vehicle weight, but there is a concern about this influencing the results of emission test, because the second-by-second rotating speed and torque in WHVC differ from those in WHTC.

We checked how the method for ensuring the consistency of positive work between WHVC and WHTC (“WHVC compensation method”) influences the results of emission tests. The results of our verification are as follows:

Fig. 1 shows the torque curves of the engine used in the engine dyno test and Table 1 the specification of the vehicle used.
The device used to after-treat the engine emission was HC-SCR. In this test, we assumed a conventional vehicle so we could check exclusively the influence of the WHVC compensation method.

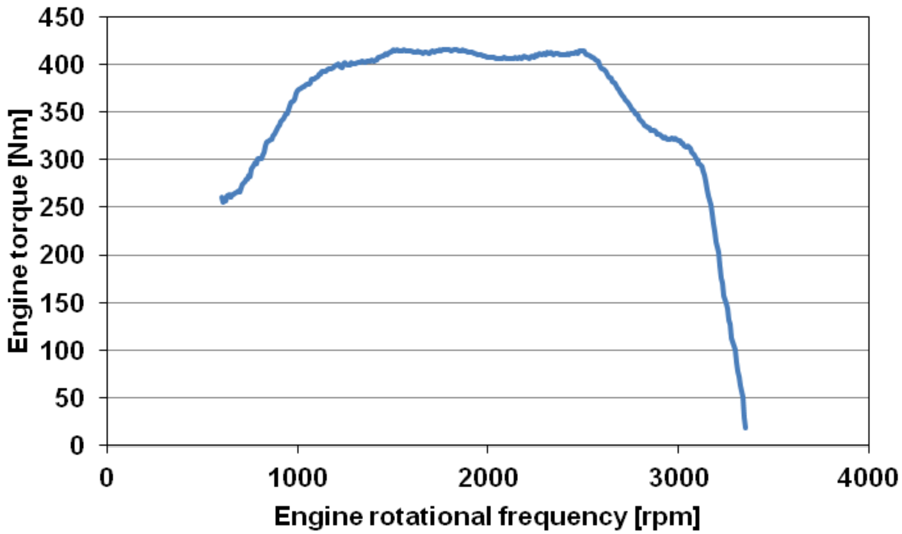

Fig. 1 Engine torque curve

Table 1 Vehicle specification

Vehicle body related	curb vehicle mass [kg]	2482
	payload [kg]	2396
	crew [persons]	3
	overall height [m]	2.106
	overall width [m]	1.78
	tire rolling radius [m]	0.343
Gearbox & differential gear	number of gear	5
	1st gear ratio	5.08
	2nd gear ratio	2.816
	3rd gear ratio	1.587
	4th gear ratio	1
	5th gear ratio	0.741
	final gear ratio	5.275
Engine type	idling engine speed [rpm]	600
	rated engine speed [rpm]	2500
	governed engine speed [rpm]	3100
	rated engine power [kW]	110
	engine capacity [L]	4

Test Conditions and Measured Items

<Test Conditions>

The engine dyno test was performed under the five conditions shown in Table 2.

Table 2 Test conditions

No.	Test cycle	Payload	Slope	Temperature conditions	Test purpose
1	WHVC	Half	Second by second	cold + hot	Reference value. Check the influence, on the emission, of when the Engine rotational frequency and torque differ between WHTC and WHVC while the matching in second by second power.
2	WHVC	Half	30-sec moving average slope	cold + hot	WHVC compensation method proposed by Japan
3	WHVC	Half	minicycle	cold + hot	WHVC compensation method proposed by Europe
4	WHVC	Maximum	0% slope	cold + hot	As a method for compensating WHVC other than providing slope, We tried changing the payload from "half payload" to "maximum payload"
5	WHTC	—	—	cold + hot	Checked difference in emission from the second by second slope

<Measured Items>

Each test measured four items: CO, THC, NOx, and PMs.

Creating the Test Cycle

The test cycle to be used in the engine dyno test was created following the steps below:

1. Calculate WHTC and convert the power from that of the system shaft to that of the wheel hub.

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2. Calculate the driving force (on the wheel hub) required while running in WHVC.

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3. Calculate the difference in power on the wheel hub between WHTC and WHVC.

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4. Calculate the slope that fills the difference in power[*1].

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5. Calculate the engine rotational frequency and torque while running in WHVC with the slope calculated above provided[*2].

*1: Used the method of calculation of 30-sec moving average slope proposed by Japan and that of mini cycle proposed by Europe.

*2: Used a program that modified the heavy duty vehicle speed conversion program indicated in Attached Sheet 3-2 to Attachment 41 so that slope resistance may be added.

To calculate the slopes proposed by Japan, it is necessary to define the negative cycle power in WHTC. To do so, the part where the torque is defined as motoring in WHTC has been replaced with the negative cycle power in WHVC of 0% slope. Further, mini cycle is calculated using not avr. WHTC but WHTC.

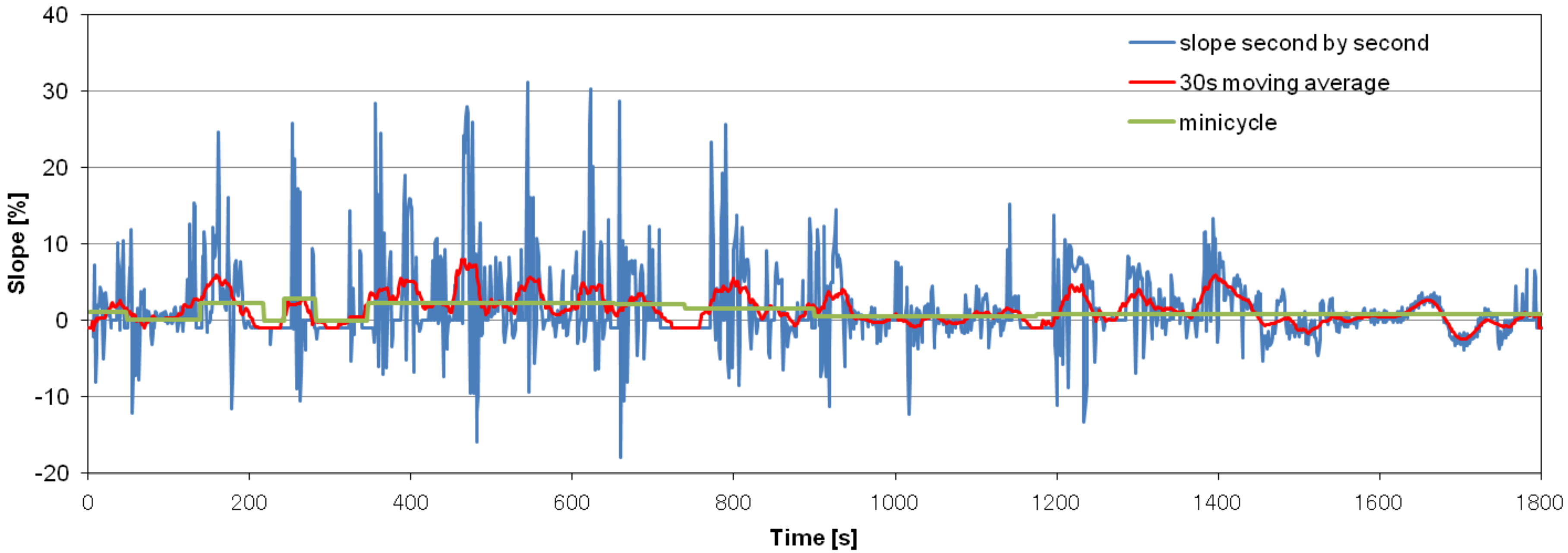

Fig. 2 Slopes used in the calculation of test cycles

The difference in positive work between WHTC and each test cycle is 0.0% in the second by second slope cycle, -0.7% in the 30-sec moving average slope cycle, +1.9% in the mini cycle, and -14.9% in the maximum pyload cycle.

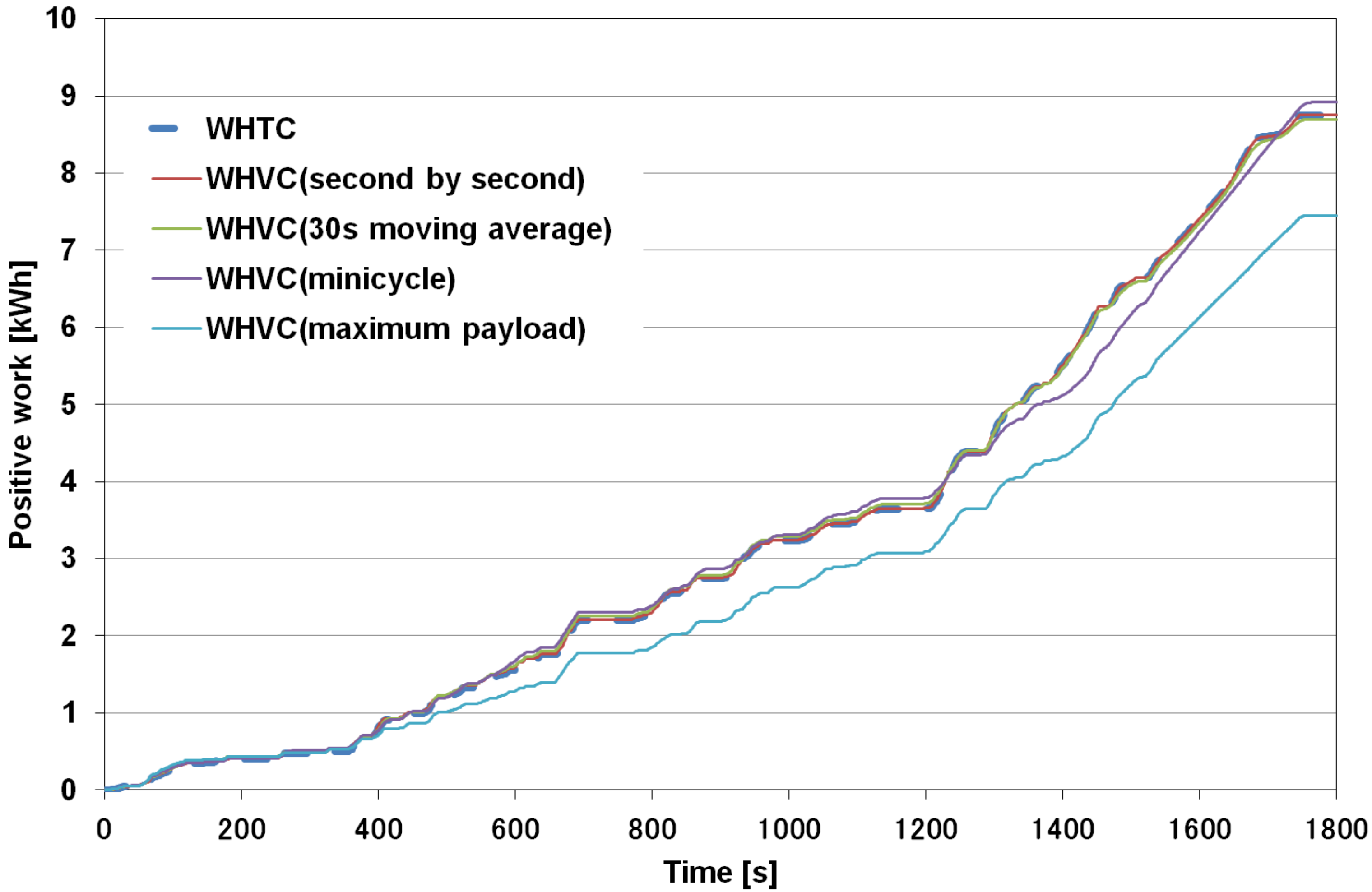

Fig. 3 Positive work in test cycles

Fig. 4 shows the results of the emission test in percentage of the second by second slope to the test results. Compared to the second by second slope, NOx was 90% in the 30-sec moving average slope cycle, 65% in the mini cycle, and 63% in the maximum payload cycle.

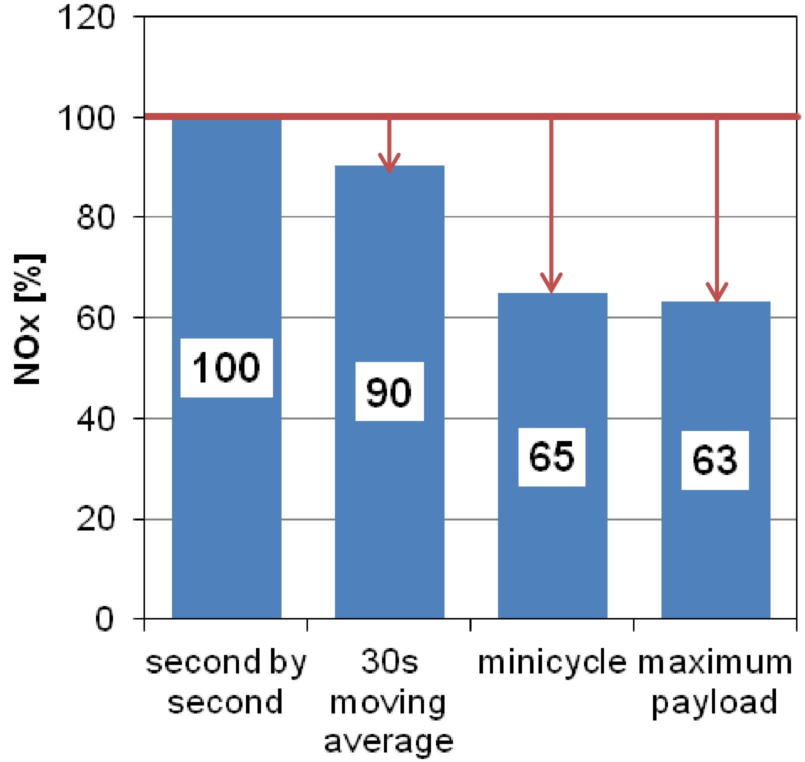

Fig. 4 NOx emission rate

The chart shows that the less the order torque value fluctuates, the lower the NOx concentration is.

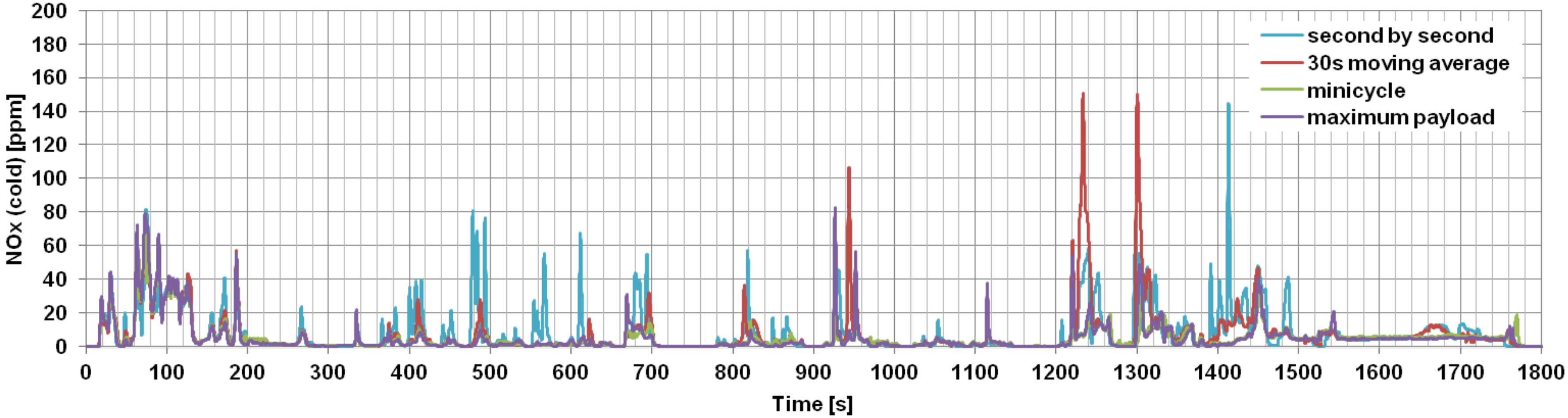

Fig. 5 NOx concentration

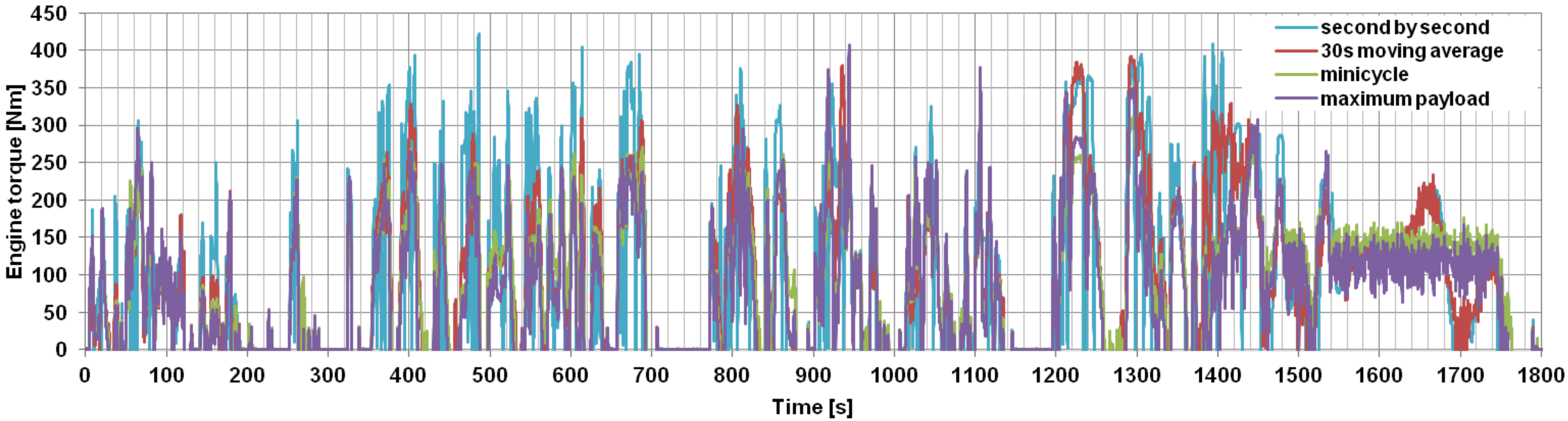

Fig. 6 Order torque value

The chart shows that the less the order torque value fluctuates, the lower the NOx concentration is (after 360 sec).

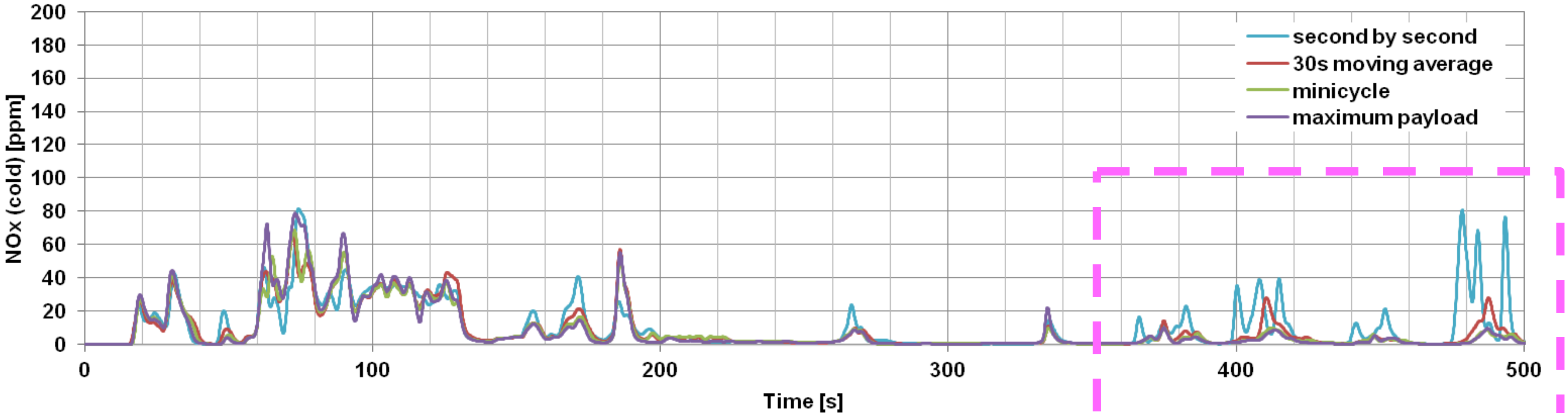

Fig. 7 NOx concentration (Closeup)

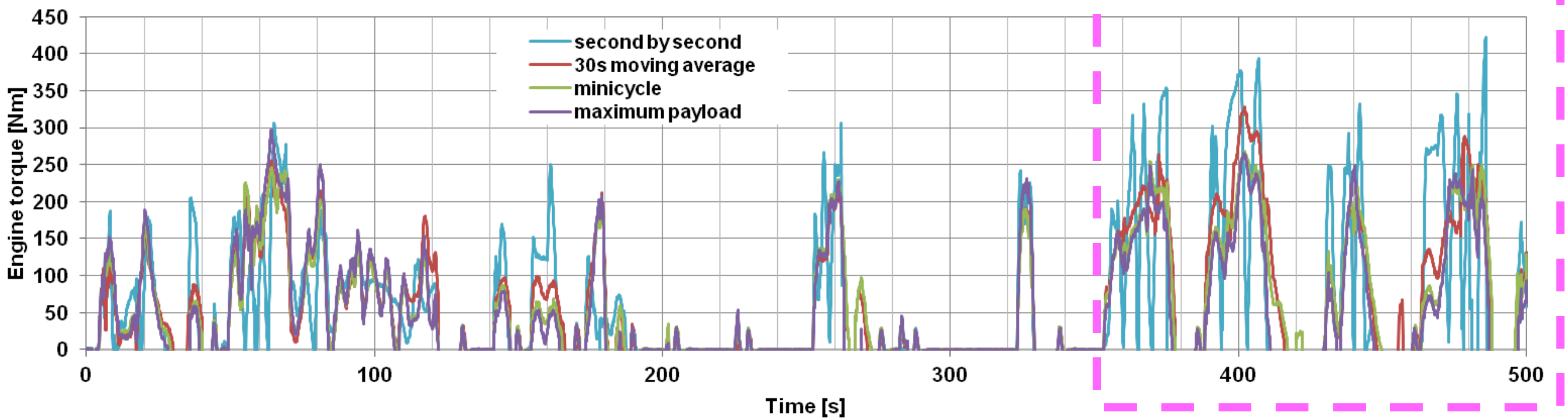

Fig. 8 Order torque value (Closeup)

Test Results (Load Frequency 1)

- The 30-sec moving average slope, whose NOx emission rate is close to that of the second by second slope, shows a load frequency distribution also close to that of the second by second slope.
- The minicycle and the maximum payload, whose NOx emission rate were lower than that of the second by second slope show the load frequency biased toward the lower torque side compared to the second by second slope.

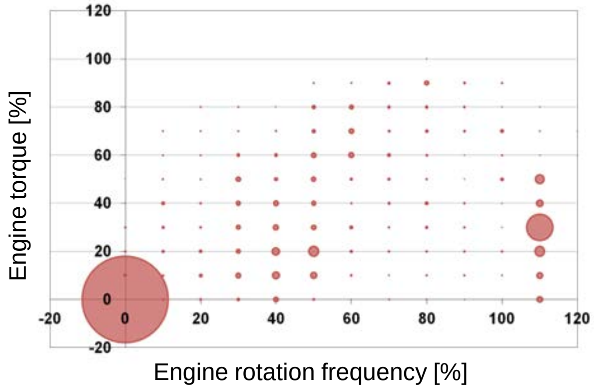

Fig. 9 second by second slope load frequency distribution

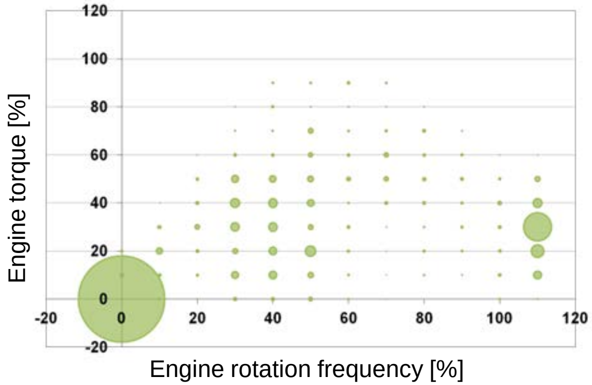

Fig. 10 30-sec moving average slope load frequency distribution

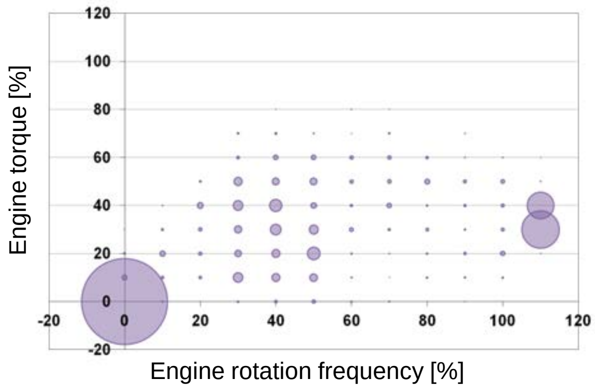

Fig. 11 Minicycle load frequency distribution

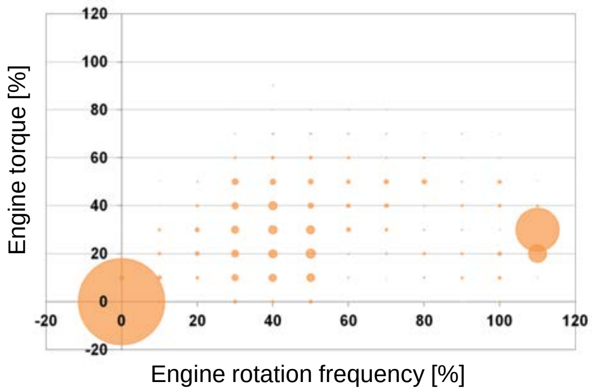

Fig. 12 maximum payload load frequency distribution

The ratio of NOx emission in second by second slope to WHTC was 77%. The rates of detection of the other emission components were very low.

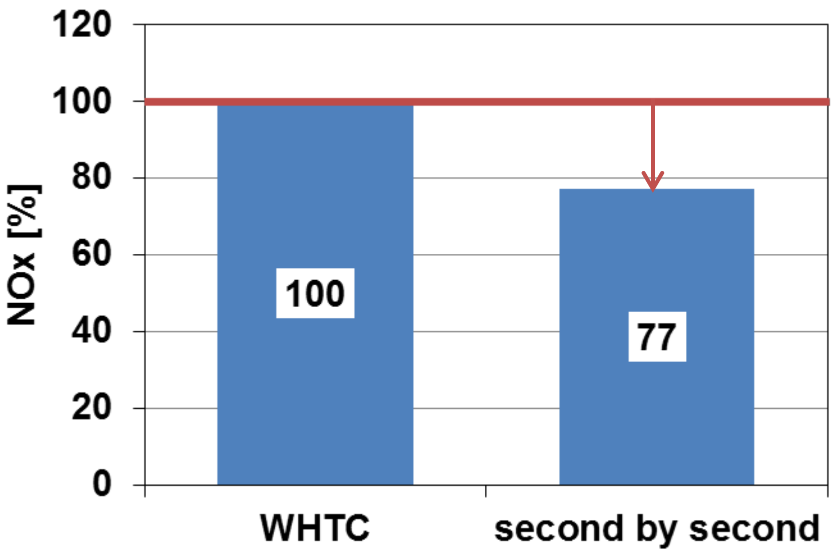

Fig. 13 Emission rate in the second by second slope compared to WHTC

The reasons the load frequency is different between the second by second slope and the WHTC while the positive work output matches seems to be the engine torque curve, shift change logic, and number of speeds.

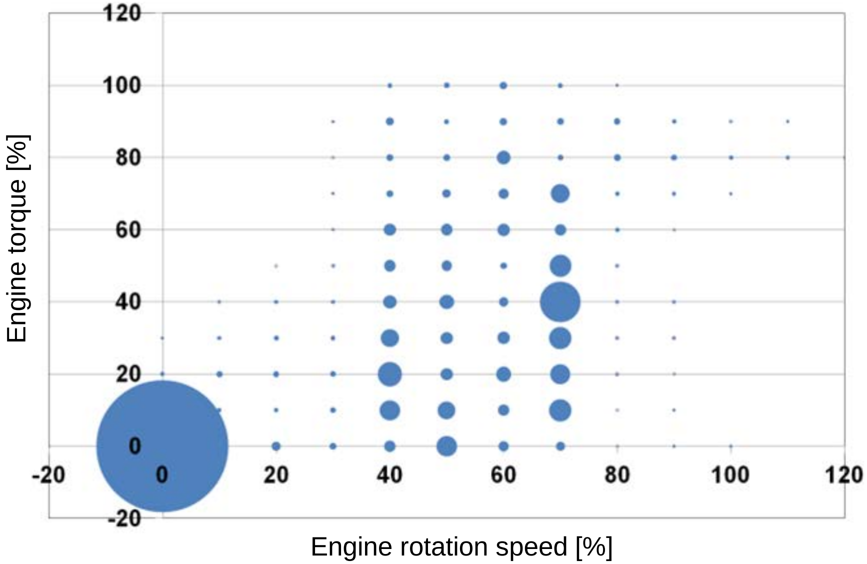

Fig. 14 Load frequency distribution in WHTC

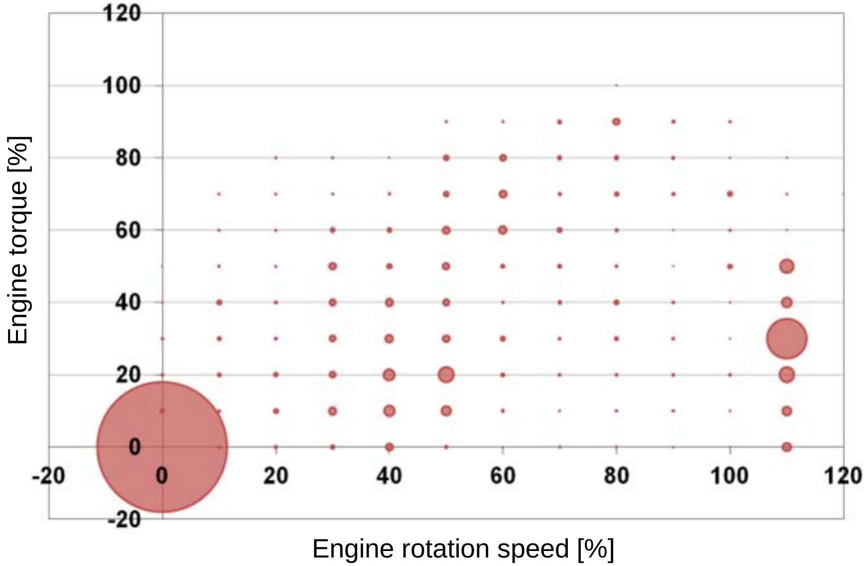

Fig. 15 Load frequency distribution in the second by second slope

Summary

An engine dyno test was conducted to check the influence of the WHVC compensation method on the results of the emission test. The test was performed in the second by second slope cycle, 30-sec moving average slope cycle, mini cycle, maximum payloaded cycle, and WHTC.

- The 30-sec moving average slope cycle showed the NOx emission rate that was closest to the second by second slope that 90%..
- The NOx emission in the second by second slope cycle reduced by 23% from WHTC. This was probably because the load frequency was distributed in an area lower than the referenced test cycle.

The load frequency depends on the torque curve and shift change logic. The test showed that the 30-sec moving average slope is closer to WHTC.

As a method for WHVC compensation method, the 30-sec moving average slope, which shows a load frequency second closest to WHTC after the second by second slope, is preferable.

Checking the Influence of Fixed Pattern Slopes on Emission Test Results

<Background of the Verification>
- The WHVC compensation methods proposed by Japan and Europe are cumbersome, because they require calculating the slope pattern for each vehicle.
- In real world, the slope of the road doesn’t change with the vehicle.
- As a certification test, it is preferable to use a single slope pattern meeting all vehicles (“fixed pattern slope”).

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We checked how the fixed pattern slope adopted as the WHVC compensation method influences the results of the emission test. The results of our verification are as follows:

<Test Conditions>

To check the influence of the fixed pattern slope on the results of the emission test, conduct a test by providing WHVC with the 30-sec moving average slope plus or minus 0.5%.

Table 3 Test conditions

No.	Test cycle	Load	Slope	Temperature conditions	Test purpose
1	WHVC	Half loaded	30-sec moving average slope	hot	Set the test reference
2	WHVC	Half loaded	30-sec moving average slope + 0.5%	hot	Check how the emission value is influenced when the slope is increased by 0.5%.
3	WHVC	Half loaded	30-sec moving average slope - 0.5%	hot	Check how the emission value is influenced when the slope is decreased by 0.5%.

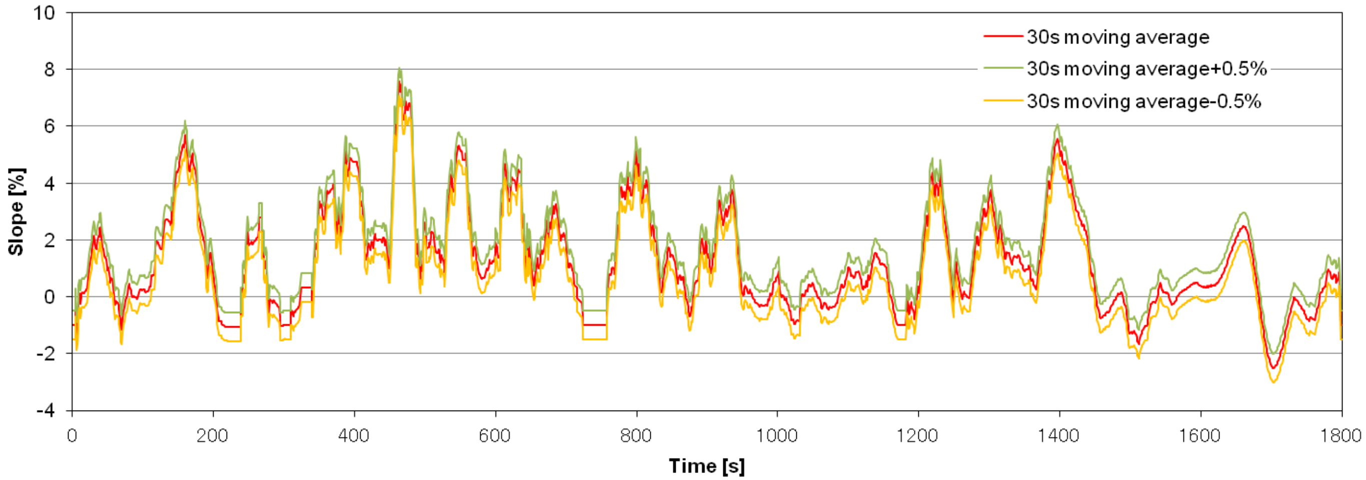

Fig. 16 Slope used in the calculation of test cycle

<Measured items>

Each test measured four items: CO, THC, NOx, and PMs.

The difference in positive work between the 30-sec moving average slope cycle and each test cycle with ±0.5% is 11.5% with +0.5% and -11.1% with -0.5%.

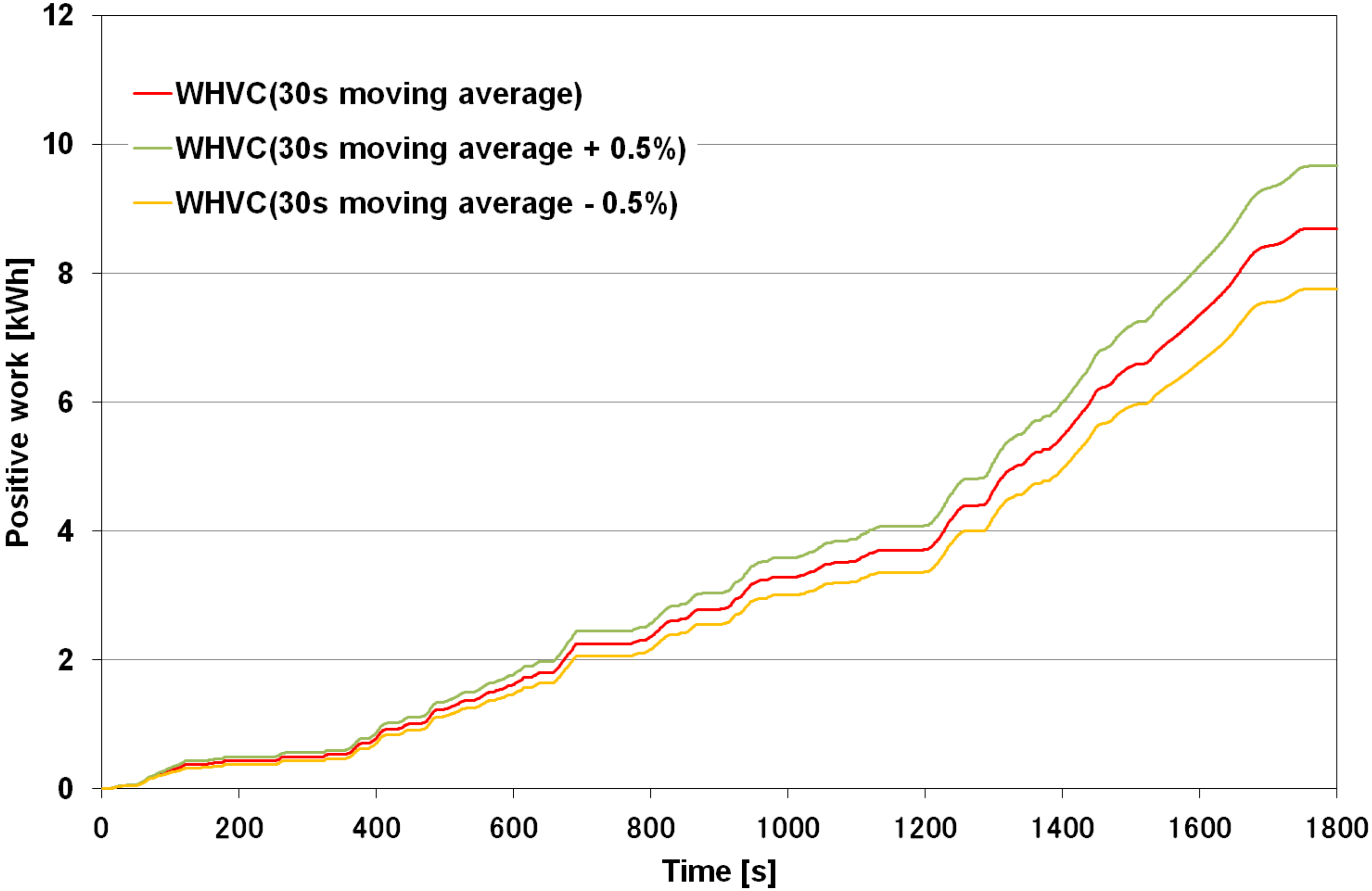

Fig. 17 Positive work in test cycles

Fig. 18 shows the results of the emission test in percentage of the 30-sec moving average slope cycle to the test results. The change in NOx emission was less than 7%.

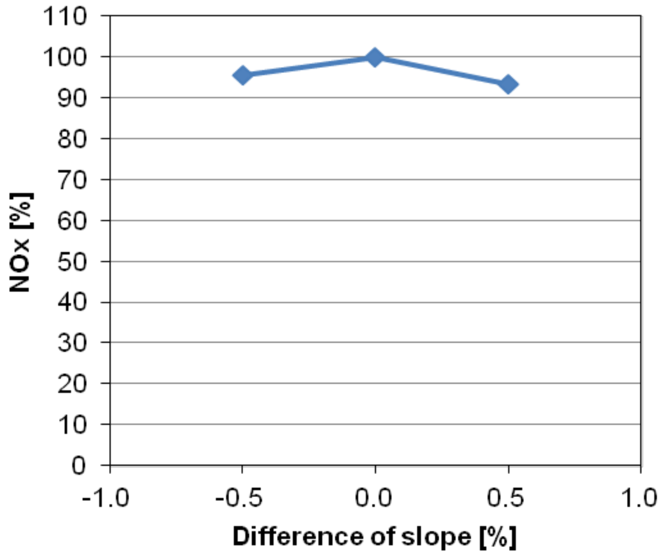

Fig. 18 NOx emission rate

To check the influence of the fixed pattern slope on the results of the emission test, a test was conducted in WHVC with 30-sec moving average slope ±0.5%. The result showed that the change in NOx emission was less than 7%.

The influence on the emission test results was minor even when the slope was increased or decreased by 0.5% and the positive work increased or decreased by 11% or so.

We find it feasible to adopt the fixed pattern slope as the slope to be given to WHVC.