F. Dell'Amico

Calspan

SIMULATION STUDY OF MOTORCYCLE RESPONSE TO PAVEMENT GROOVING

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Calspan Report No. ZN-5740-V-1

Prepared for:
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FOREWORD

This report describes a brief study performed by the Transportation Safety Department of Calspan Corporation for the Texas Transportation Institute (TTI) of Texas A&M University during the period 29 May 1975 to 29 September 1975. This work was done in support of Contract No. DOT-FH-11-8267, "Effects of Pavement Grooving on Friction, Braking, and Vehicle Control." The Calspan internal authorization number was 364.

This report has been reviewed and approved by:

Edwin A. Kidd

Edwin A. Kidd, Head
Transportation Safety Department

The handling characteristics of all vehicles are affected in some way by pavement grooving. The effects of grooving on motorcycle handling can be particularly serious due to the motorcycle's lack of inherent roll stability in comparison with four-wheeled vehicles.

The intent of this study was to determine whether the negative effects of grooved pavement on motorycycle handling, as generally reported by motorcycle riders, could be minimized or eliminated through changes in motorcycle parameters. This was to be determined by simulating the response of a motorcycle to a grooved pavement section using a digital computer simulation. The simulation program used was the Calspan motorcycle dynamics computer simulation program, which was modified for this study. The program is described briefly in Appendix A and in greater detail in Reference 1. The modifications made to the program will be described later. The motorcycle data used for the simulation were chosen to approximate a Yamaha RD 350, which was the motorcycle used during full scale testing by TTI. The physical properties of the simulated motorcycle, which are given in Appendix B, came from three sources:

- Motorcycle inertial data and motorcycle tire data came from a data set for a Honda CB360G motorcycle, which is similar in size and weight to the Yamaha. This data set was originally prepared for use in Contract No. DOT-HS-4-00976 and reported in Reference 2.

- Motorcycle geometric data (wheelbase, rake, trail, etc.) came from a road test of a Yamaha RD 350 B which appeared in the December 1974 issue of Cycle magazine (Reference 3).

- Rider weight was provided by TTI.

The simulated maneuver was the traversal of a section of grooved pavement by a motorcycle running in a straight line. Steering torque data were obtained in full-scale tests by TTI by means of a torque sensor located between the handlebars and front fork of the test motorcycle. This experimentally recorded torque signal was then digitized and used as a disturbance input to the motorcycle computer simulation.

The steering torque signal was applied in the simulation as a moment acting about the motorcycle's steer axis. The motorcycle simulation program was modified to permit the input of this external torque through the addition of two subroutines and revisions made to several others. One of the new subroutines read the digital tape and stored the input signals in an array for later use in the simulation and in output. Input to this subroutine consisted of the time on the tape at which the simulation t_0 would occur, the time at which grooving was encountered, a parameter to instruct the simulation whether or not to use the pavement grooving function, and the values of the constant parameters in the grooving function.

The second of the new subroutines applied the torque signal to the motorcycle's steering system. One of the revisions made to the programs allowed the taped values of steering torque and steer angle to be printed and plotted, together with the normal output. Another was the inclusion of the TTI pavement grooving function to modify the front and rear tire side forces. This function is as follows:

$$F_{y_{grooved}} = e^{0.638} \cdot \alpha^{-0.0116} \cdot \gamma^{-0.0124} \cdot AA^{0.0308} \cdot F_z^{-0.0671} \cdot \mu_x^{0.0176} \cdot C_\gamma^{0.0874} \cdot PF^{-0.2618} \cdot F_y^{1.0095}$$

where: α = Tire slip angle (degrees)
γ = Tire inclination angle (degrees)
AA = Groove approach angle (degrees)
F_z = Tire normal force (pounds)

μ_x = Maximum normalized camber thrust (lb/lb)

C_γ = Normalized camber coefficient (lb/deg/lb)

PF = Pavement factor

F_y = Ungrooved tire side force (lb)

During all runs made in this study, the following parameters in the above equation were held constant:

Approach Angle		1.0 degree
μ_x max (camber)	front	0.7
	rear	0.7
Camber Coefficient	front	0.02 lb/deg/lb
	rear	0.01 lb/deg/lb
Pavement factor		0.75

The simulated motorcycle was upright and at steady state at the beginning of each simulation run, with the values of the state variables and their derivatives set equal to zero.[*] The taped torque input was then applied and the motorcycle allowed to respond to the torque with no rider control inputs. The time histories of 31 different parameters were printed out for each simulation run. In addition to the printed output, time history plots of several important parameters were made. These parameters and their titles on the plots are: the input steer torque from the tape (STR TORQ), the experimental value of steer angle from the tape (STR(EXP)), the simulated steer angle (STR(SIM)), the simulated roll angle (ROLL), and the simulated yaw angle (YAW). The plots for all the simulation runs are given in Appendix C. Table 1 summarizes the run conditions for the simulation runs made during the study.

The results of the study are rather inconclusive. Because the only parameter available for comparing simulated and experimental results is the steer angle, no firm conclusions can be reached as to how well this method of simulating grooved pavement response on the computer compares with full scale test results. It is noted, however, that the agreement between simulated

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[*] Except for initial forward velocity, which was 70 miles per hour for all runs.

Table 1 COMPUTER STUDY RUN CONDITIONS

Run No.	Tape No.	File No.	Tire Press (psi)	Steer Damper	Tape Time at Start of Simulation (sec)	Simulation Run Time (sec)	Simulation Time at Start of Grooving (sec)	Grooving Function Used	Motorcycle Configuration
1	ZZ3340	2	12	OUT	6.005	4.5	0.670	YES	STANDARD
2	ZZ3340	1	12	IN	7.651	4.5	0.660	YES	STANDARD
3	ZZ3340	2	12	OUT	6.005	4.5	0.670	YES	ZERO STEER DAMPIN
4	ZZ3341	1	22	OUT	3.642	4.8	2.241	YES	ZERO STEER DAMPIN
5	ZZ3340	1	12	IN	4.015	4.8	4.296	YES*	STANDARD
6	ZZ3575	3	12	OUT	2.010	4.8	2.256	YES*	STANDARD
7	ZZ3575	4	12	OUT	6.305	4.8	2.256	YES	ZERO STEER DAMPIN
8	ZZ3575	3	12	IN	2.010	4.8	2.256	NO	STANDARD
9	ZZ3340	2	12	OUT	6.005	4.8	0.670	NO	STANDARD
10	ZZ3575	5	22	OUT	0.000	4.8	1.875	YES	STANDARD
11	ZZ3575	5	22	OUT	0.000	4.8	1.875	NO	STANDARD
12	ZZ3575	3	12	IN	2.010	4.8	2.256	YES	STANDARD
13	ZZ3575	4	12	OUT	6.311	4.8	2.250	YES	STANDARD
14	ZZ3575	4	12	OUT	6.311	4.8	2.250	NO	STANDARD

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*In these runs, probable errors in the event channel of tape ZZ3575 caused the grooving function not to start at the same time the motorcycle encountered the grooved pavement.

and experimental steer responses is not particularly good for any of the simulation runs. No actual oscillations of the motorcycle that could be termed weave or wobble were noted, either in the simulated or experimental steering time histories.

The lack of correlation between simulation and experiment for Runs 1-5 led to the theory that the high frequency content of the torque signal was masking the frequencies tending to induce an oscillation in the motorcycle. As an attempt to correct this condition, the data was low-pass filtered with a 30 Hz cutoff frequency to produce tape ZZ3575. This tape contained the same data as the previous two unfiltered tapes (ZZ3340 and ZZ3341). The results using the filtered data produced much the same results as the unfiltered data.

One conclusion that can be reached is the effect of the grooving function on the motorcycle response. The run conditions for runs 1 and 9, 8 and 12, 10 and 11, and 13 and 14 are identical except for the use of the grooving function. Comparison of the plotted results from these runs shows virtually identical responses. It can be concluded therefore that the grooving power law has very little effect on motorcycle response under the conditions used in this study.

It is evident that more work is needed to study the influence of pavement grooving on motorcycle handling, especially since handling differences are noted by test riders; the limited resources of this program were not equal to the task of providing a satisfactory solution to this problem.

REFERENCES

1. Roland, R. Douglas, "Computer Simulation of Bicycle Dynamics," Symposium on Mechanics and Sport, Applied Mechanics Division, The American Society of Mechanical Engineers, New York, November 11-15, 1973.

2. Rice, Roy S.; Davis, James A.; and Kunkel, Dennis T.; "Accident Avoidance Capabilities of Motorcycles - Technical Report," Calspan Report No. ZN-5571-V-1, June 1975.

3. Anon., "Road Test - Yamaha RD 350 B," Cycle magazine, December 1974, Volume 25, No. 12, P44.

APPENDIX A

SIMULATION DESCRIPTION

In this appendix, the characteristics of Calspan's motorcycle simulation program are discussed in general terms to demonstrate its capability to treat various operating condtions and control modes. The description of the mathematical model on which it is based is quite brief; it is described in more detail in Reference 1.

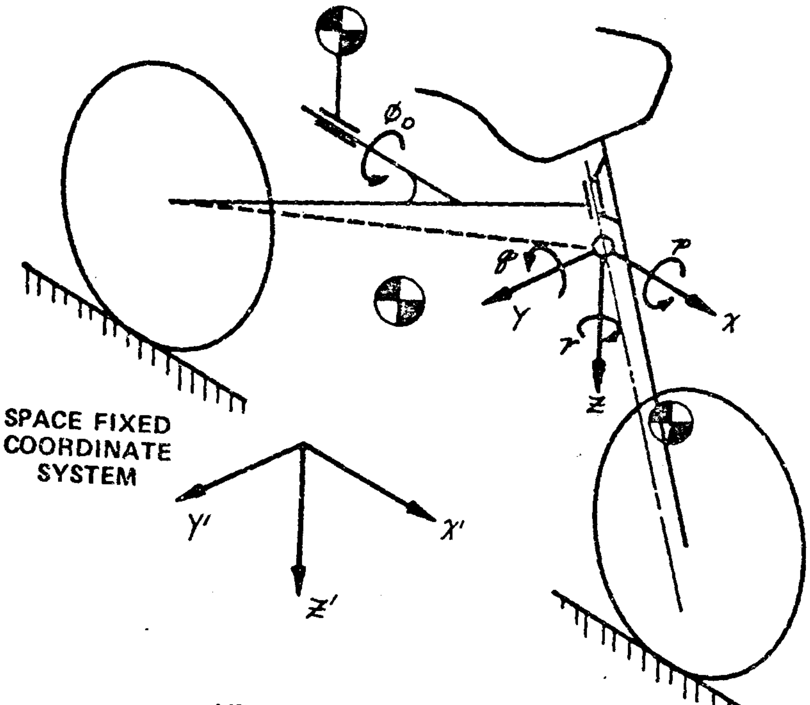
The vehicle-rider model is a system of three rigid masses with eight degrees of freedom of motion: six rigid-body degrees of freedom of the rear frame, a steer degree of freedom of the front wheel, and a rider lean degree of freedom (see Figure A1. The basic physical parameters of the vehicle which are included in the mathematical analysis are shown in Figure A2, where Θ_F is the rake angle of the steer axis and δ is the steer angle of the front wheel about the inclined steer axis. The symbols M_D, M_R, M_F represent the masses of the rider, the rear wheel and frame, and the front wheel and steering fork assembly, respectively.

The analysis is based on the following assumptions:

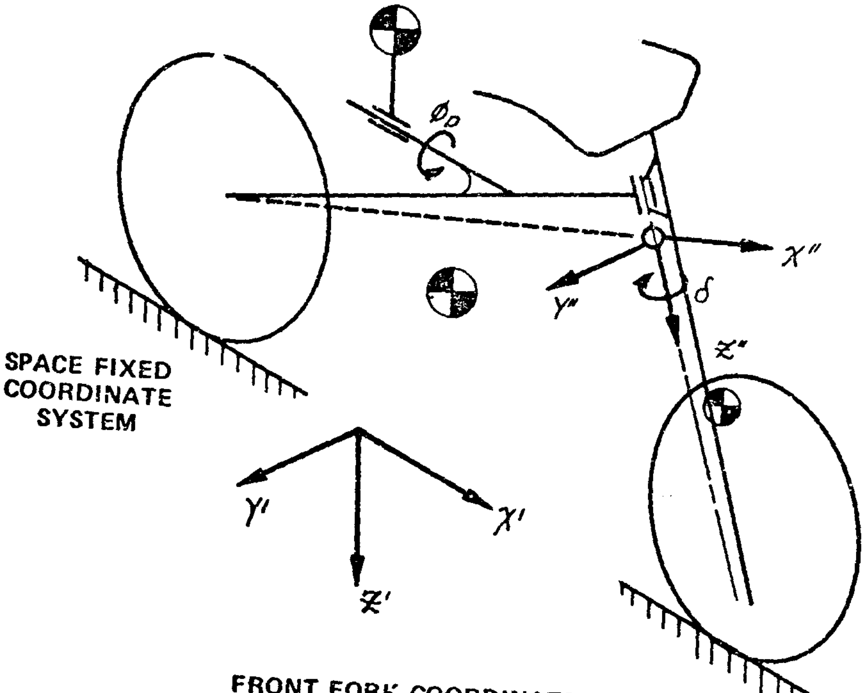
(1) The mass distribution of the vehicle is assumed to be symmetrical with respect to the vertical-longitudinal plane through the geometrical center of the vehicle. Thus, the X-Y and Y-Z products of inertia are assumed to be zero. X-Z products of inertia and all moments of inertia of each rigid mass are included.

(2) The vehicle is assumed to be moving through still air on a flat level surface. The aerodynamic drag, the front to rear weight transfer due to aerodynamic drag, and the pitching moment, aerodynamic lift, and steer moment due to windshield aerodynamic drag are included as approximations.

(3) A driving thrust on the rear wheel is included to overcome the aerodynamic drag. Thus, the vehicle is initially moving at constant speed. Front tire rolling resistance is assumed negligible.



VEHICLE COORDINATE SYSTEM



FRONT FORK COORDINATE SYSTEM

Figure A1 Two-Wheel Vehicle Model

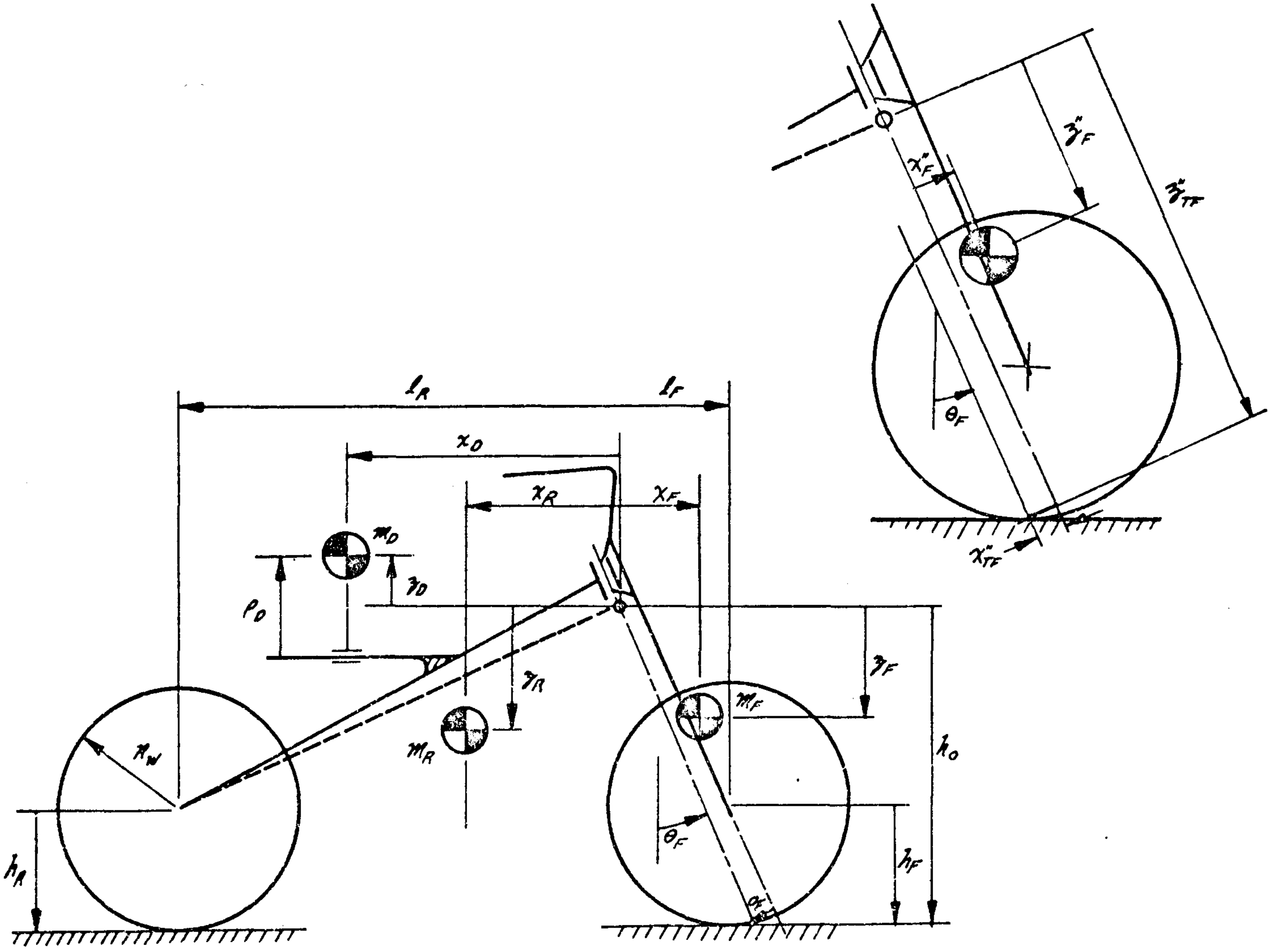


Figure A2 . Characteristic Dimensions of Motorcycle Model

(4) Tire lateral forces as functions of slip angle, inclination (camber) angle, and vertical load are modeled independently for front and rear tires.

(5) External torques acting about the steer axis include the moments due to the lateral and vertical tire forces, tire aligning torque, and a couple due to the aerodynamic drag force on the windshield. The gyroscopic moments of the wheels and engine are included.

(6) Viscous steering damping is included between the front assembly and the rear frame.

(7) The axis of rotation of the engine is assumed to be transverse with the direction of rotation of the engine the same as that of the wheels.

To analyze the handling of a two-wheel vehicle in the nonlinear region of operation, the equations of motion are written in complete nonlinear form. All inertial coupling terms between the rider, the front assembly, and the rear frame are included. The digital computer simulation program for this analysis solves the equations of motion for prescribed rider control inputs and/or disturbance inputs and produces time histories of the resultant vehicle motions.

The simulation program, consisting of twelve subroutines, uses approximately 200 K bytes of core storage when run on an IBM System/370 Model 165 computer. The output processor program uses approximately 160K bytes of core storage.

Over one hundred input variables are required by the simulation program. These data include forty-six vehicle parameters: dimensions, weights, moments of inertia, tire side force coefficients, aerodynamic coefficients, etc.

The digital computer simulation program consists basically of the application of a modified Runge-Kutta step-by-step procedure to integrate the equations of motion. The integration step size is a variable although a value of 0.01 second is generally used. The solution of up to 10 seconds of simulated real time may be obtained with a step size of 0.01 second. Solution output is obtained from a separate output processor program which can produce time histories of as many as 36 variables (translational and angular positions, velocities, accelerations, tire force components, etc.) in both printed and plotted format.

APPENDIX B

SIMULATION INPUT DATA

MOTORCYCLE DYNAMICS COMPUTER SIMULATION INPUT FORM

IDENTIFICATION FIELDS:*

YAMAHA RD350 72

BASELINE DATA SET 72

1. GENERAL VEHICLE PARAMETERS:

Wheelbase (in)	9	52.0	+
Total Weight (lb)	17	352.0	+
Portion of Total Motorcycle Weight on the Front Wheel (Percent)	25	45.0	
Location of Total C.G. Above Ground (in)	33	18.0	
Total Roll Moment of Inertia About Axis Through Total C.G. (lb-in-sec^2)	41	80.0	
Total Pitch Moment of Inertia About Axis Through Total C.G. (lb-in-sec^2)	49	280.0	
Total Yaw Moment of Inertia About Axis Through Total C.G. (lb-in-sec^2)	57	255.0	
Total Roll-Yaw Product of Inertia About Axis Through Total C.G. (lb-in-sec^2)	65	0.0	80 1
Weight of Front Fork Assembly (Fork, Wheel, Handlebars, Windshield) (lb)	9	65.0	
Perpendicular Distance From C.G. of Front Fork Assembly to Steer Axis (in)	17	2.6	

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*These two cards must be included in every data set (even if blank). They make available a total of 144 columns for identification of vehicle configuration, run no., etc., at user's discretion. The information entered will appear at the top of each sheet of computer printout and at the top of each plot.

Distance Parallel to Steer Axis From C.G. of Front Fork Assembly to Front Wheel Center (in)	25 12.5
Roll Moment of Inertia of Front Fork Assembly About an Axis Perpendicular to the Steer Axis Through C.G. of Assembly (lb-in-sec^2)	33 34.0
Pitch Moment of Inertia of Front Fork Assembly About an Axis Perpendicular to the Steer Axis Through C.G. of Assembly (lb-in-sec^2)	41 36.0
Yaw Moment of Inertia of Front Fork Assembly About the Steer Axis (lb-in-sec^2)	49 5.5
Roll-Yaw Product of Inertia of Front Fork Assembly About an Axis Through the C.G. of the Assembly (lb-in-sec^2)	57 0.0 | 2 80

2. RIDER PARAMETERS:

a. Standard Rider Model:

Weight of Rider (lb)	9
Portion of Rider Weight on Front Wheel (percent)	17
Height of Rider C.G. Above Ground (in)	25
Height of Saddle Above Ground (in)	33
Roll Moment of Inertia of Rider About an Axis Through His C.G. (lb-in-sec^2)	41
Pitch Moment of Inertia of Rider About an Axis Through His C.G. (lb-in-sec^2)	49
Yaw Moment of Inertia of Rider About an Axis Through His C.G. (lb-in-sec^2)	57
Roll-Yaw Product of Inertia of Rider About an Axis Through His C.G. (lb-in-sec^2)	65 | 3 80

b. Alternate Rider Model		-1	8
Height of Rider (in)	9	72.0	
Weight of Rider (lb)	17	200.0	++
Height of Saddle Above Ground (in)	25	31.0	+
Location of Saddle Forward of Rear Wheel ℄ (in)	33	9.0	
Height of Foot Pegs Above Ground (in)	41	12.0	
Location of Foot Pegs Forward of Rear Wheel ℄ (in)	49	21.0	
Height of Handgrips Above Ground (in)	57	40.0	
Location of Handgrips Forward of Rear Wheel ℄ (in)	65	31.0	3 80

3. FRONT FORK PARAMETERS:

Caster Angle of the Steer Axis (deg)	9	27.5	+
Nominal Steering Trail (in)	17	3.7	+
Front Tire Pneumatic Trail (in)	25	0.8	
Steering Viscous Damping Coefficient (in-lb/deg/sec)	33	0.5	
Steering Hydraulic Damping Coefficient (in-lb/deg^2/sec^2)	41	0.0	
Spin Moment of Inertia of Front Wheel (lb-in-sec^2)	49	4.0	
Spin Moment of Inertia of Rear Wheel (lb-in-sec^2)	57	8.0	
Front Tire Lateral Force Runout (lb)	65	0.0	4 80

4. AERODYNAMICS PARAMETERS:

Aerodynamic Drag Coefficient (dimensionless)	9		
Aerodynamic Lift Coefficient (dimensionless)	17		
Total Frontal Area (in^2)	25		
Lateral Offset of C.P. From Motorcycle ℄ (in)	33		
Height of Center of Pressure Above Ground (in)	41		
Aerodynamic Drag Coef. of Windshield (dimensionless)	49		
Frontal Area of Windshield (in^2)	57		
Location of Windshield C.P. Forward of Steer Axis (in)	65		5 80

7. PATH INPUT DATA:

Number of Path Segments	8

X and Y Coordinates of Path Segment Junction Points

(The Number of Sets of Coordinates Must Be One Greater Than The Number of Path Segments)

X	Y	
9	17	
25	33	
41	49	
57	65	10 80
9	17	
25	33	
41	49	
57	65	11 80
9	17	
25	33	
41	49	
57	65	12 80

8. TIRE PARAMETERS:

	FRONT		REAR	
Undeflected Tire Rolling Radius (in)	9 12.5		9 12.6	
Tire Section Width (in)	17 3.00		17 3.50	
Radial Stiffness of Tire (lb/in)	25 600.0		25 850.0	
Radial Damping Coefficient of Tire (lb/in/sec)	33 0.0		33 0.0	
Slip Angle - Tire Side Force Coefficient (lb/lb/deg)	41 0.3		41 0.24	
Slip Angle Cubed - Tire Side Force Coefficient (lb/lb/deg^3)	49 -0.001		49 -0.0008	
Inclination Angle - Tire Side Force Coefficient (lb/lb/deg)	57 0.02		57 0.01	
Tire Relaxation Length (in)	65 0.0	13 80	65 0.0	14 80

END OF VEHICLE INPUT DATA*	9999	80

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*This card must be included in every data set.

NOTE:

DATA IS ASSUMED FROM MEASURED HONDA CB-360G DATA EXCEPT:

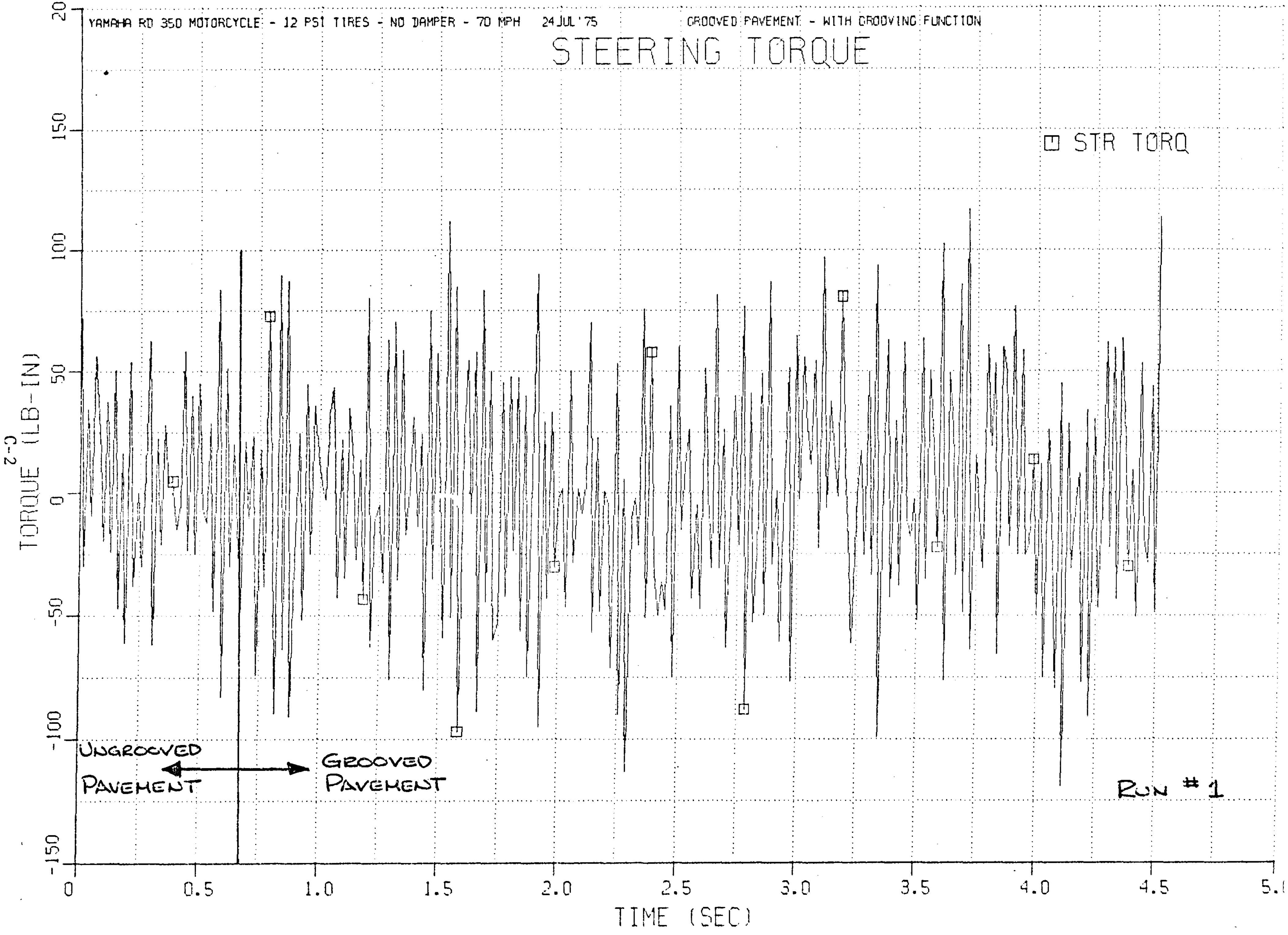
+ - FROM DEC. 74 CYCLE ROAD TEST ++ - FROM TTI

APPENDIX C

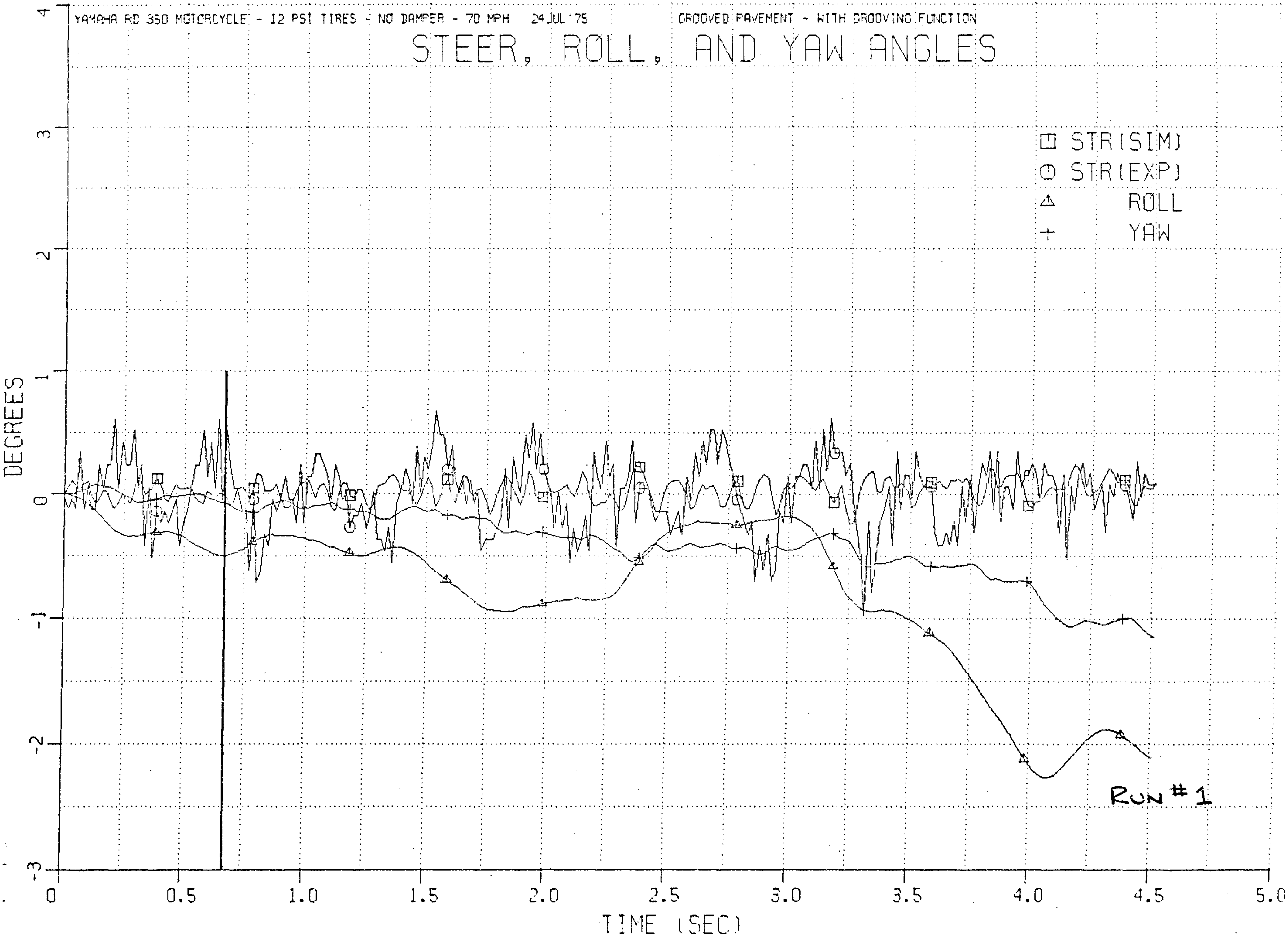
PLOTTED RESULTS OF SIMULATION STUDY

TT11

TST=6.005   TGR=.67

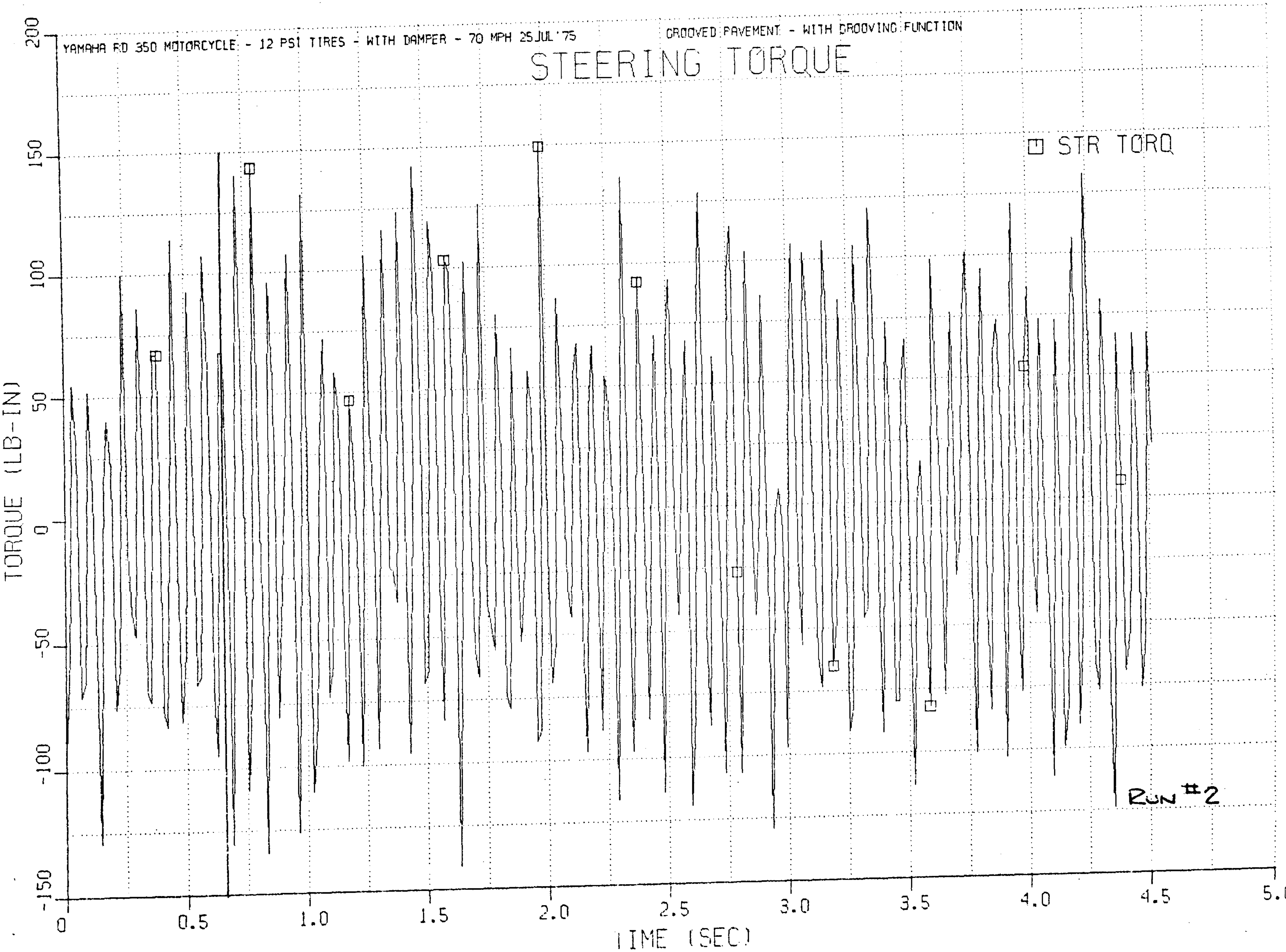


TT11

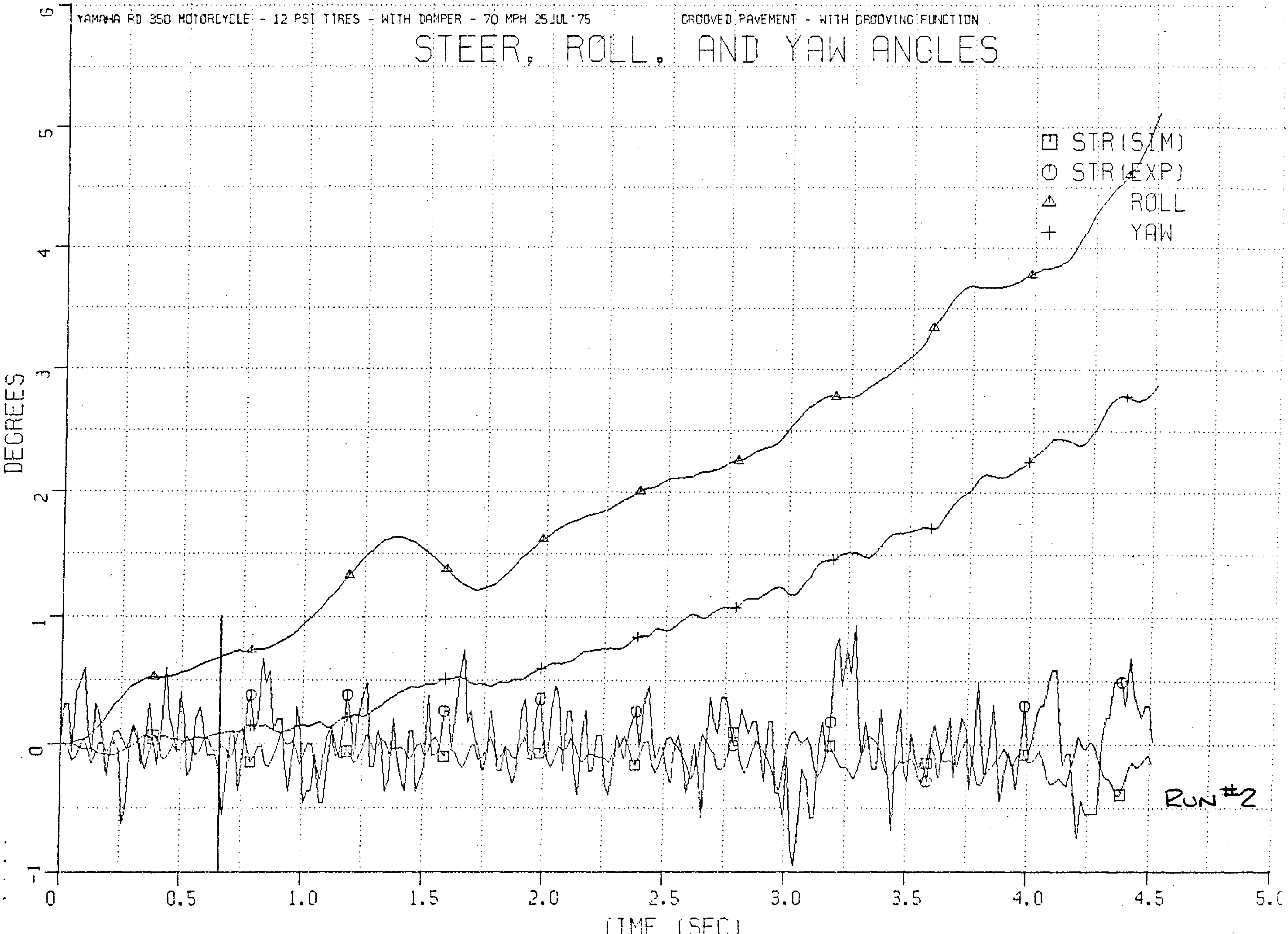

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 24 JUL '75
GROOVED PAVEMENT - WITH GROOVING FUNCTION
STEER, ROLL, AND YAW ANGLES
⊞ STR(SIM)
⦶ STR(EXP)
△ ROLL
+ YAW
DEGREES
4
3
2
1
0
-1
-2
-3
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

Run # 1

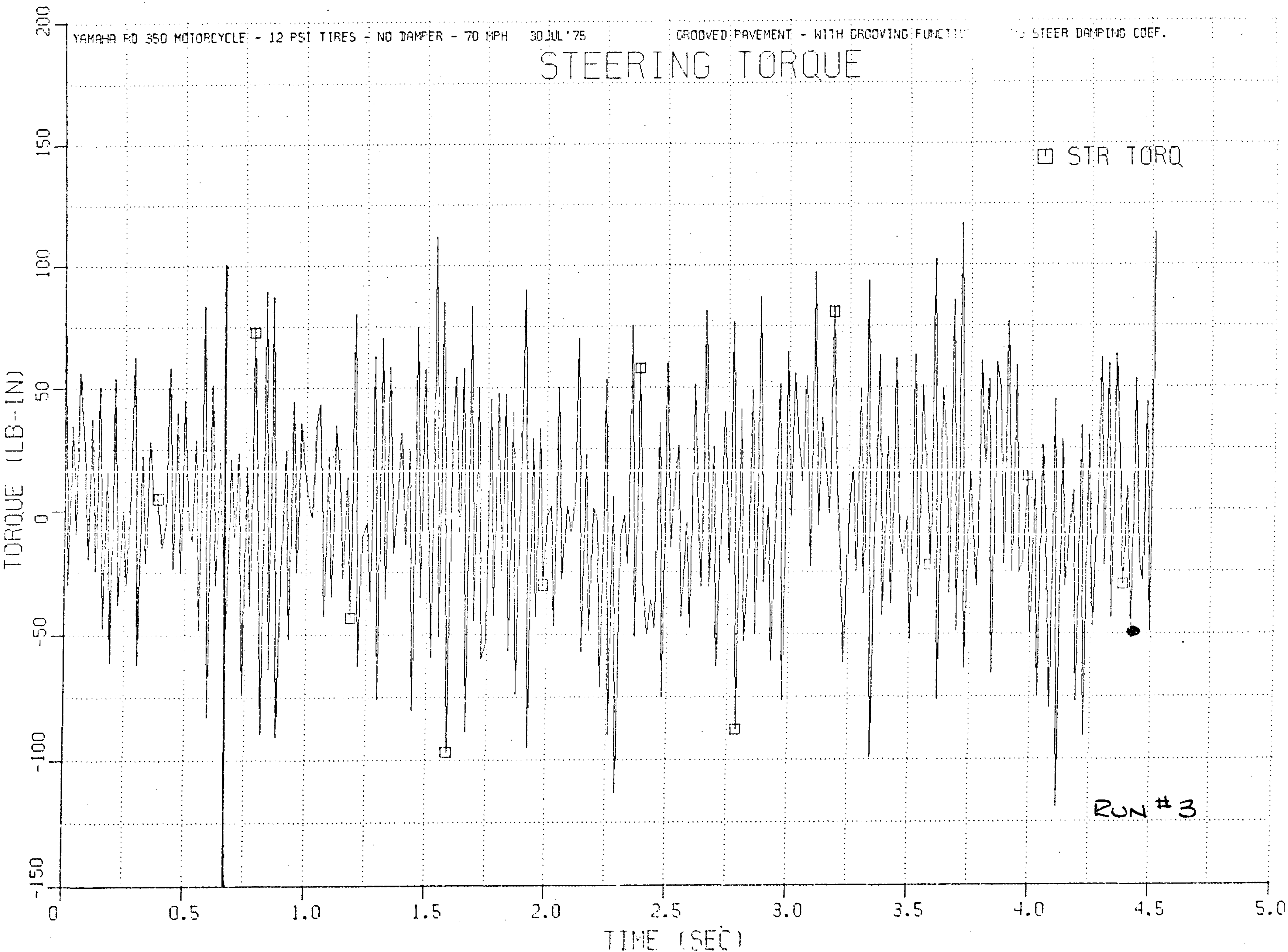
TT12
TST=7.651   TGR=0.66



TT12


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 25JUL'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION
STEER, RØLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ RØLL
+ YAW
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)
RUN #2

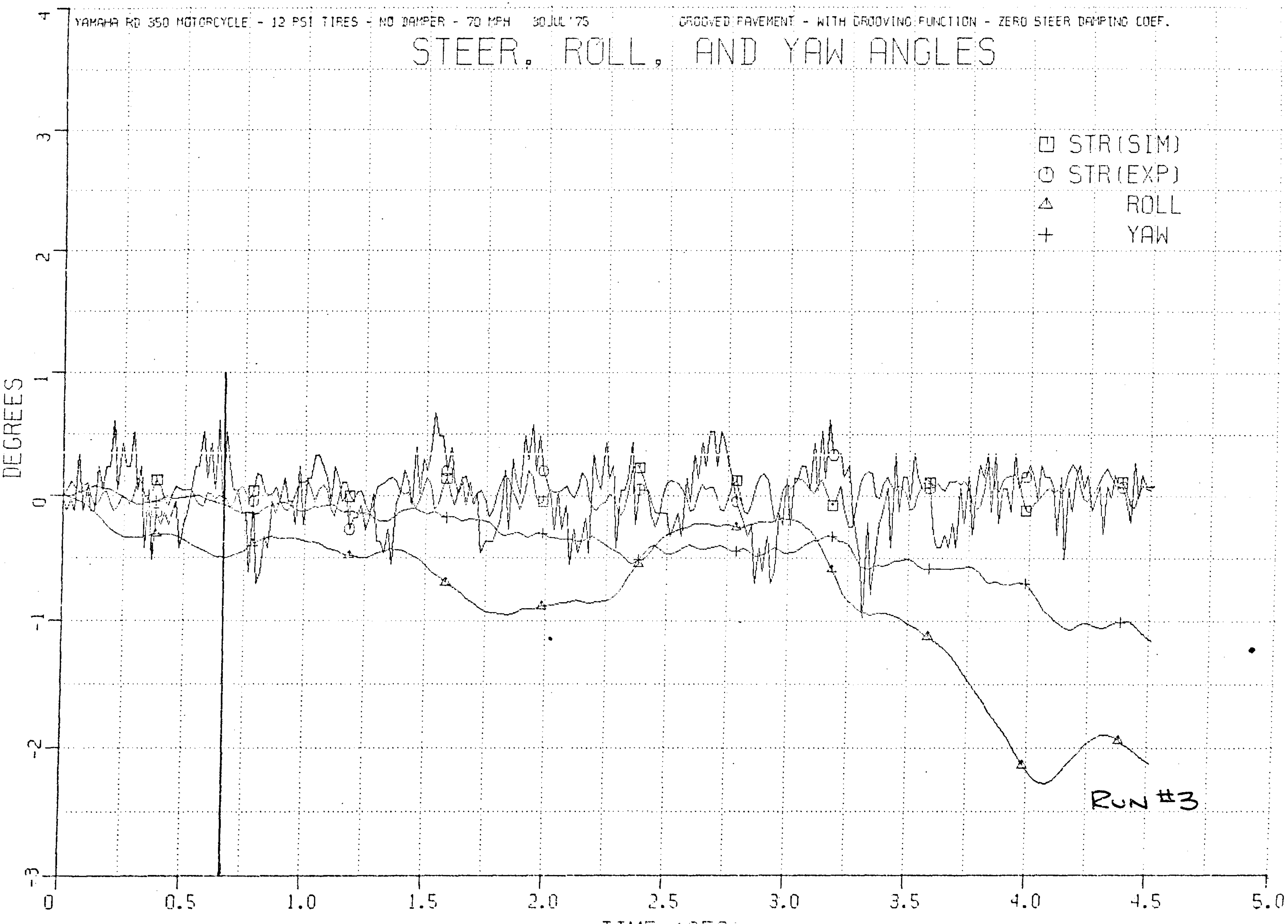
TT13


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 30JUL'75
GROOVED PAVEMENT - WITH GROOVING FUNCTI
STEER DAMPING COEF.
STEERING TORQUE
☐ STR TORQ
TORQUE (LB-IN)
200
150
100
50
0
-50
-100
-150
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

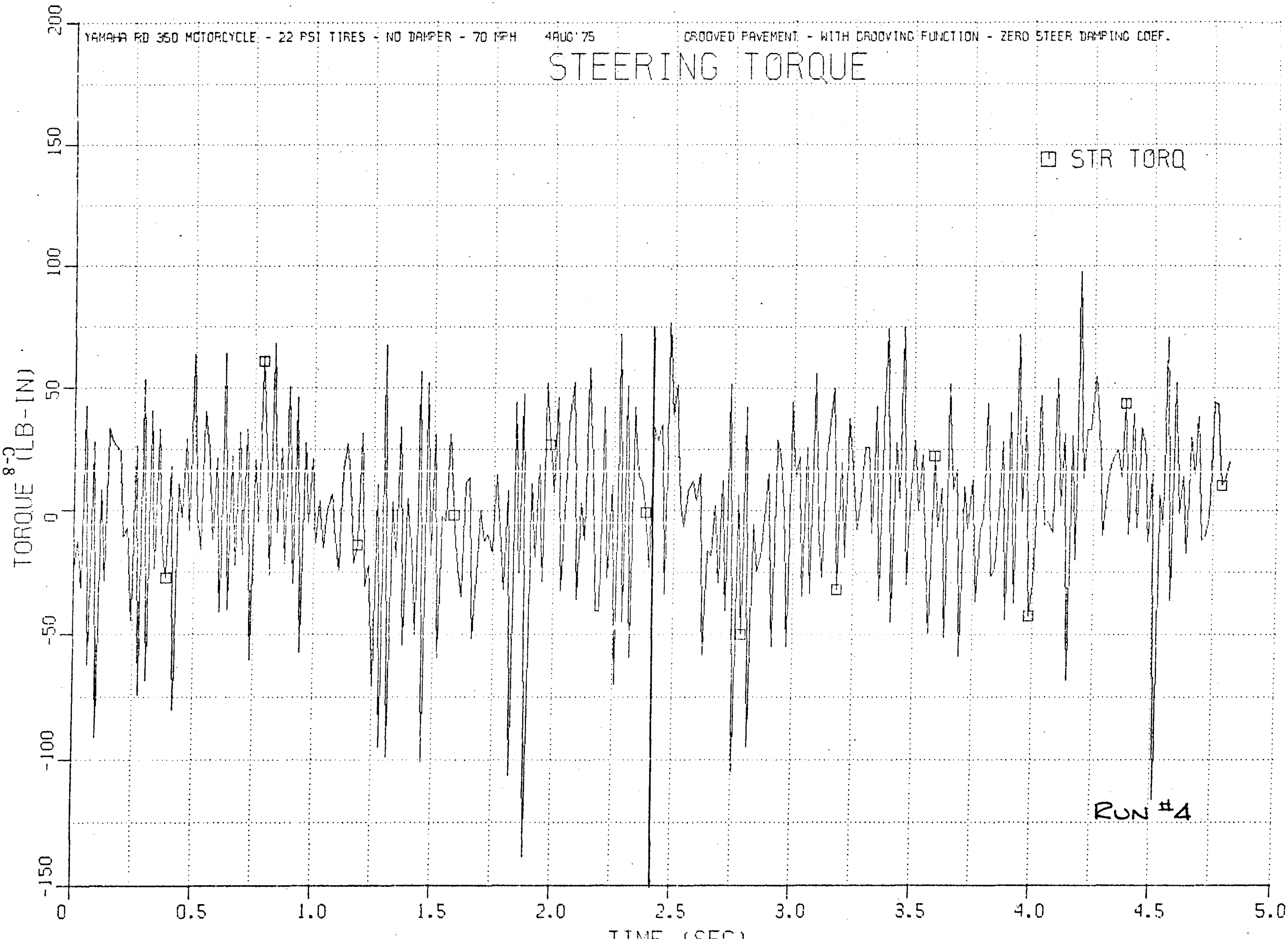
RUN #3

TT13

TST=6.005   TGR=0.67



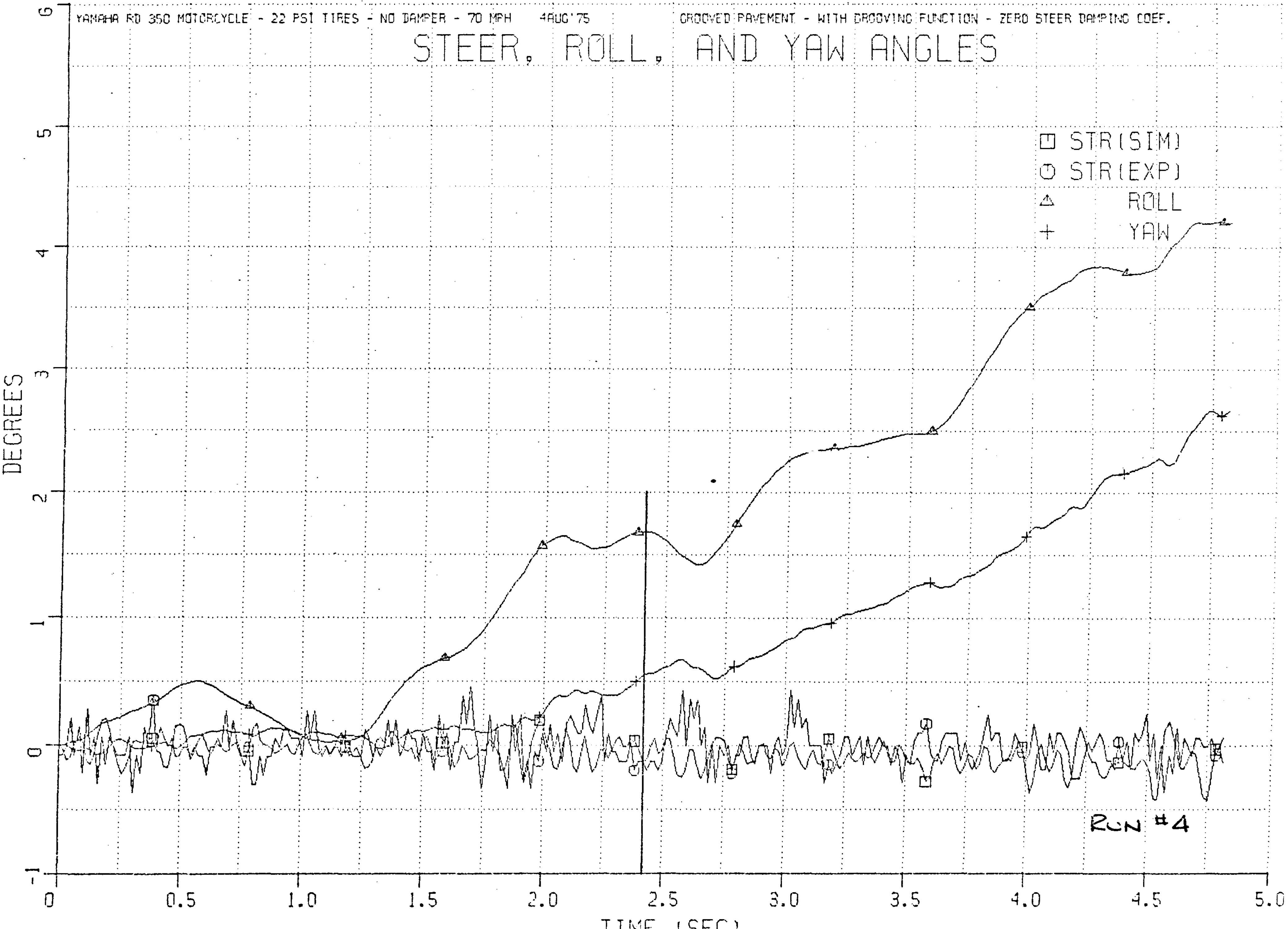
TT14

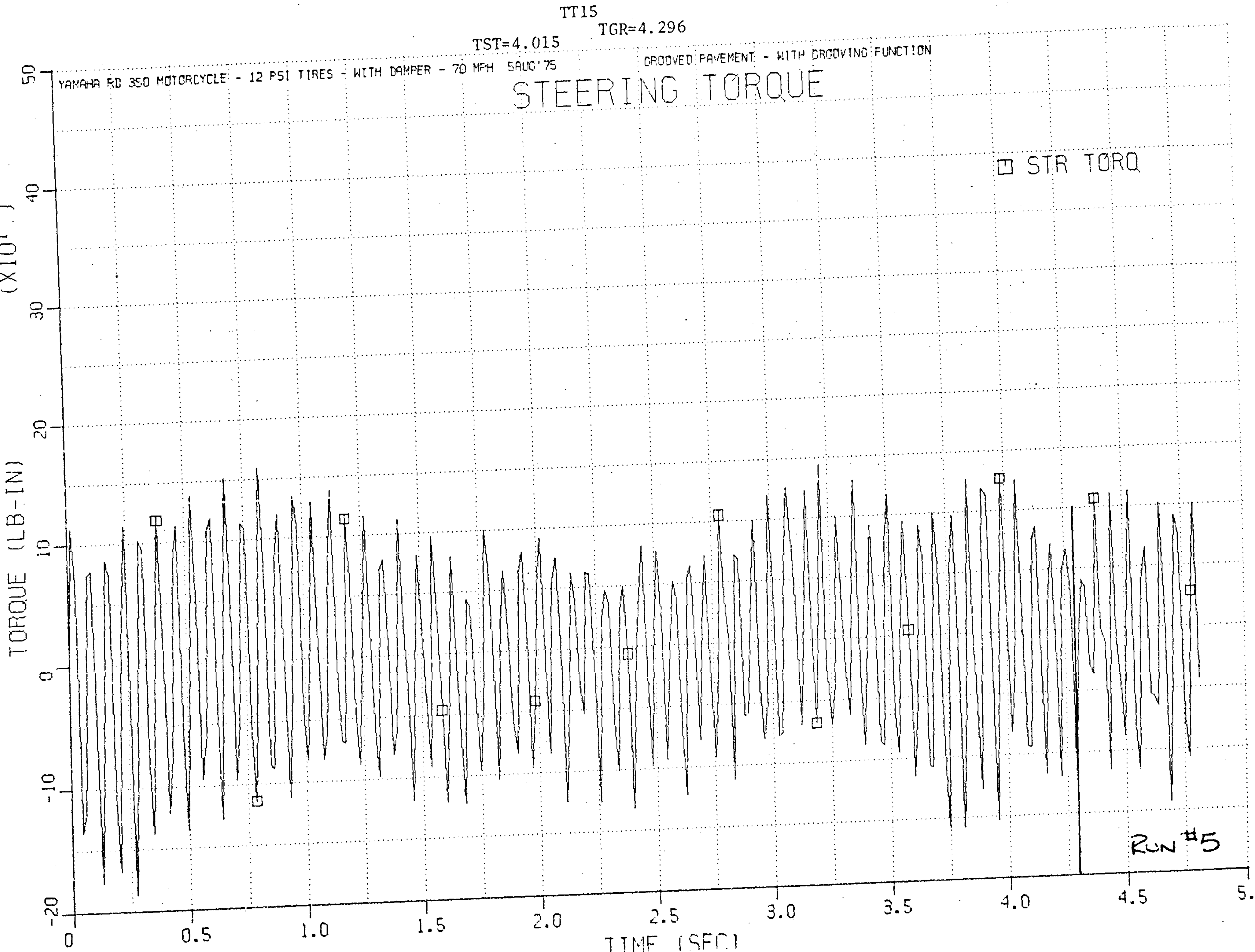


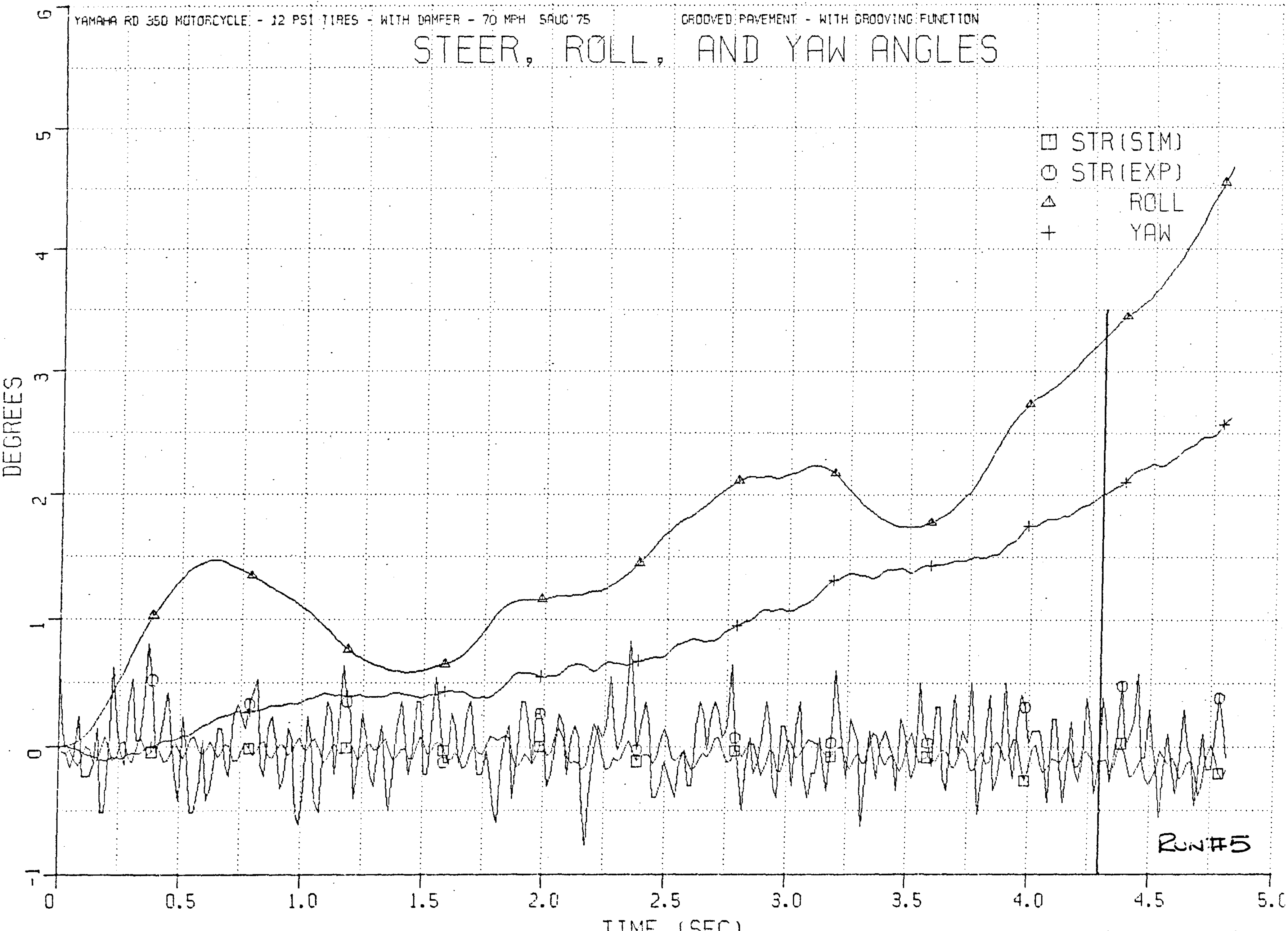
YAMAHA RD 350 MOTORCYCLE - 22 PSI TIRES - NO DAMPER - 70 MPH 4AUG'75 GROOVED PAVEMENT - WITH GROOVING FUNCTION - ZERO STEER DAMPING COEF.

STEERING TORQUE

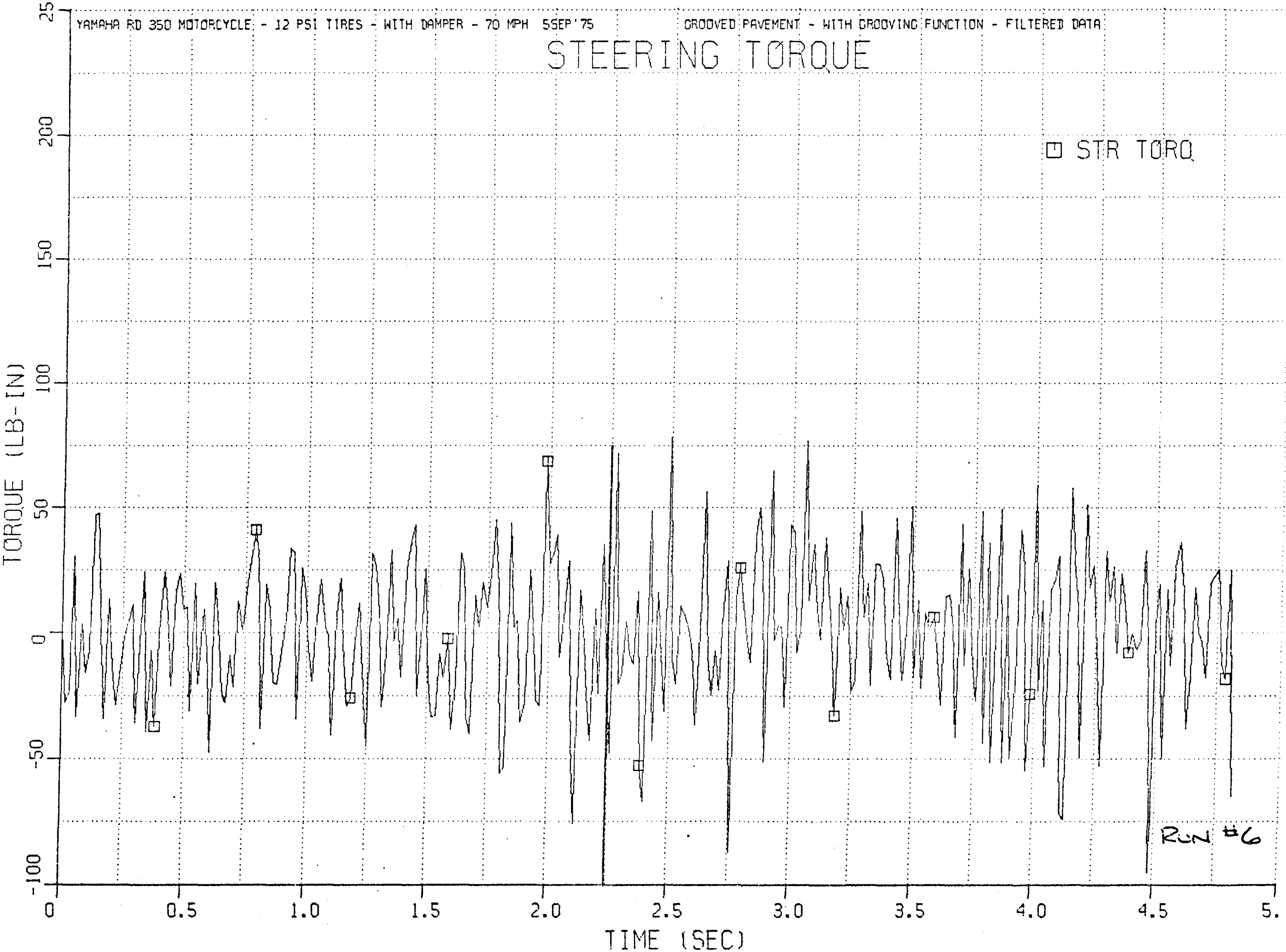
TT14
TST=3.642 TGR=2.421




TT15
TGR=4.296
TST=4.015
YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 5AUG'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION
STEERING TORQUE
☐ STR TORQ
TORQUE (LB-IN)
(X10^1)
50
40
30
20
10
0
-10
-20
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.
TIME (SEC)
Run #5

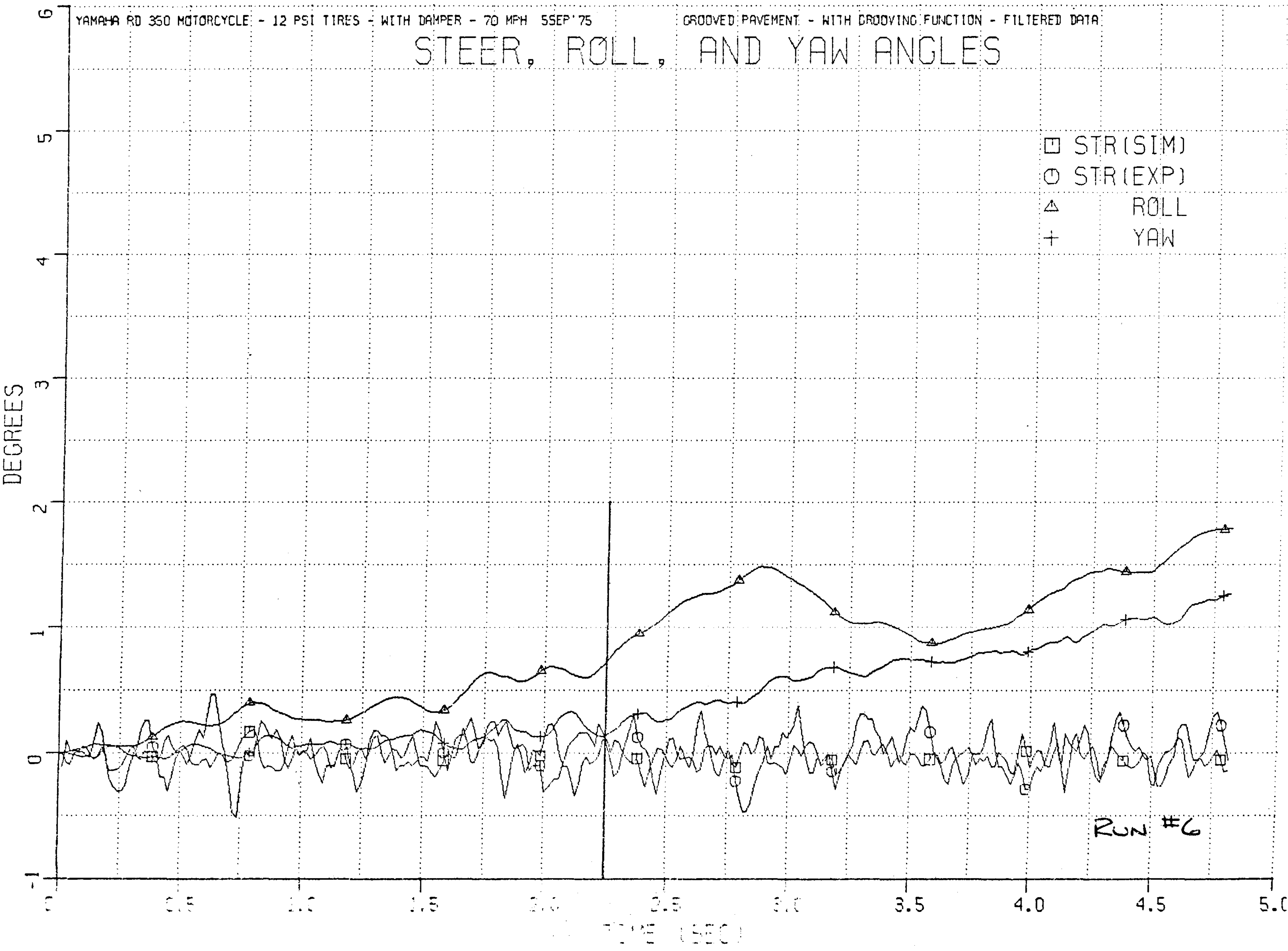

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 5AUG'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION
STEER, ROLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
TIME (SEC)
-1
0
1
2
3
4
5
6
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
RUN #5

TT16

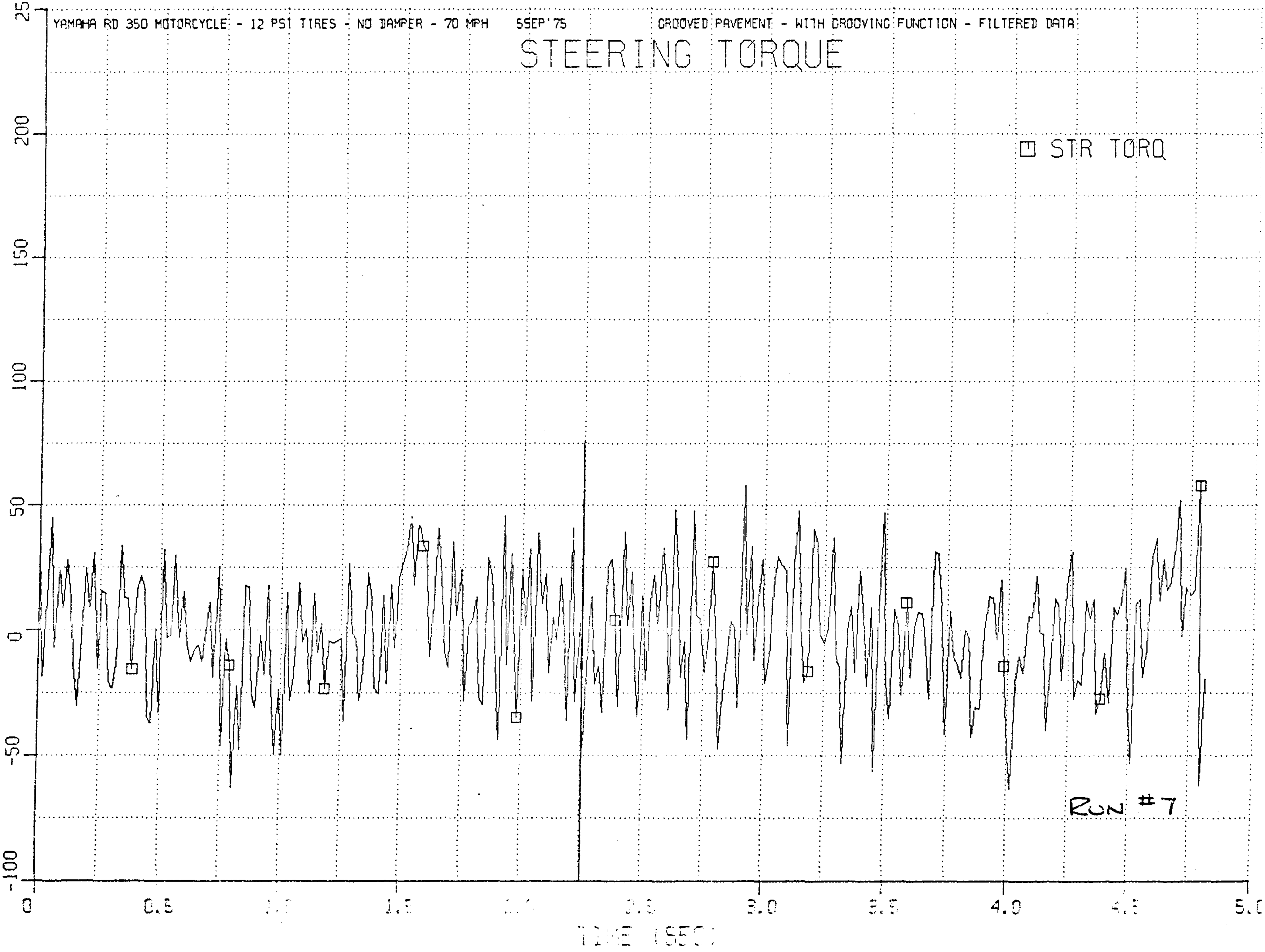

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 5SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEERING TØRQUE
☐ STR TØRQ
TØRQUE (LB-IN)
250
200
150
100
50
0
-50
-100
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.

Run #6

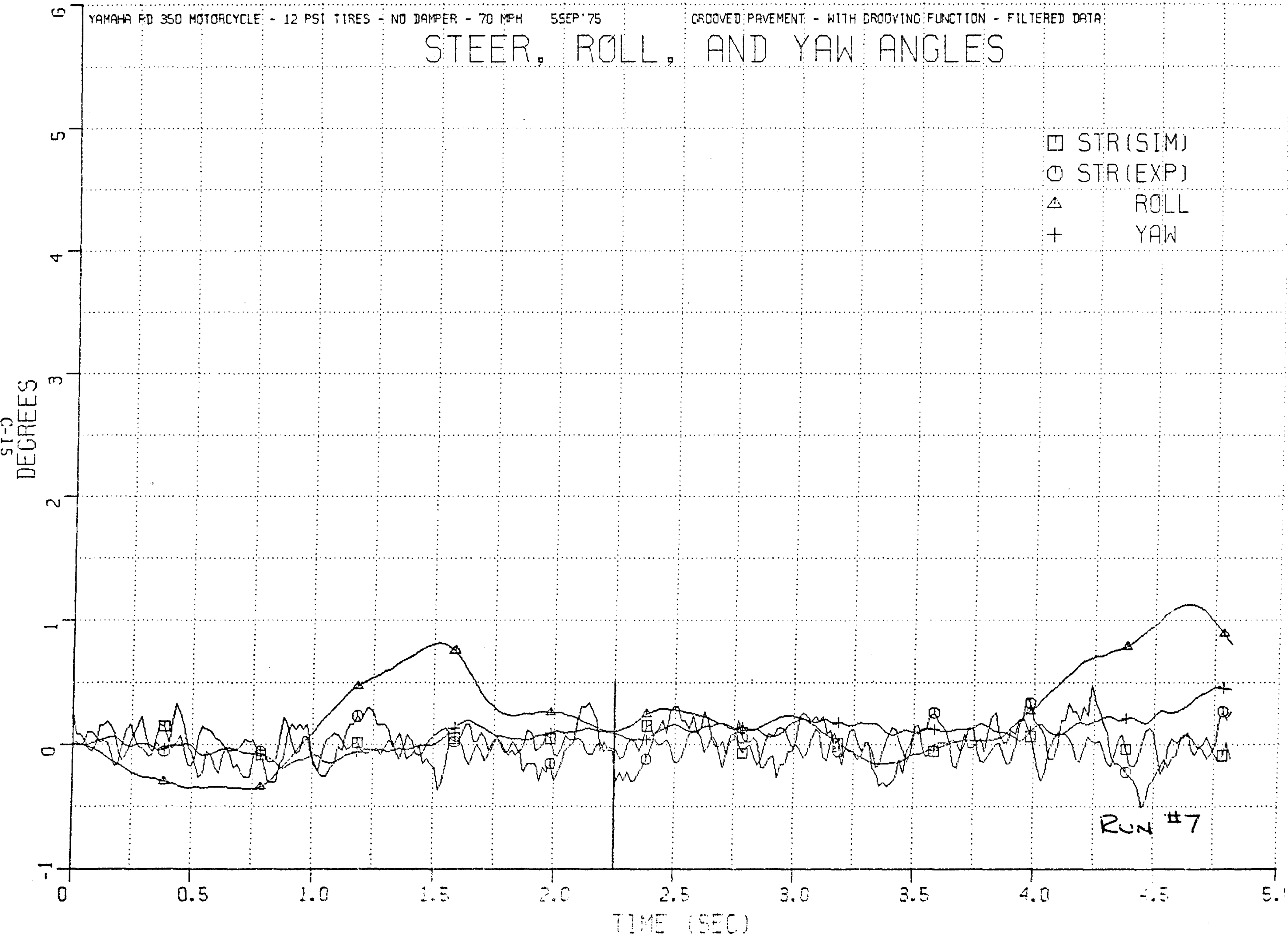
TT16


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 5SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, RØLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ RØLL
+ YAW
RUN #6
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

TT17

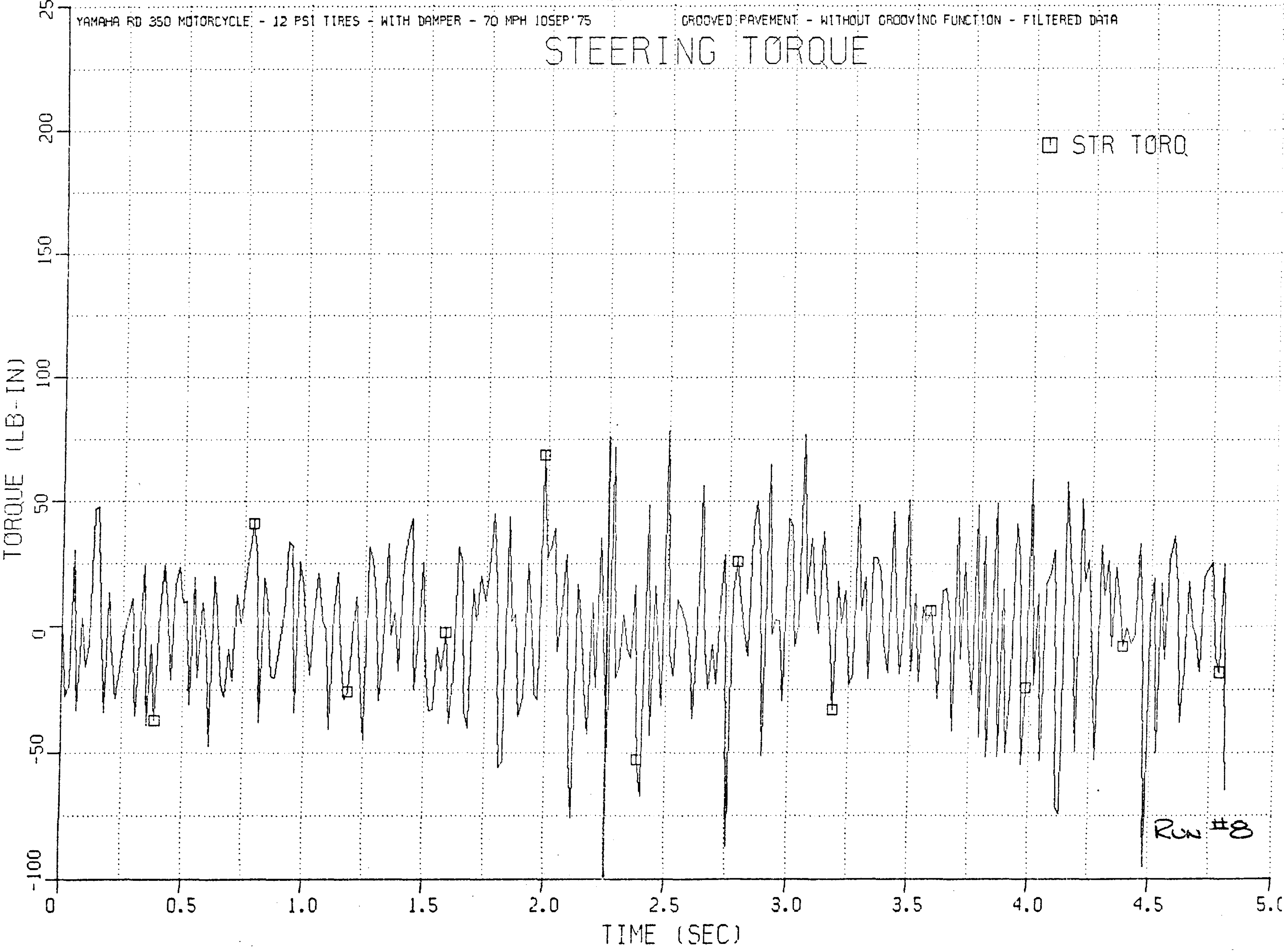

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 5SEP'75 GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEERING TORQUE
STR TORQ
TORQUE (LB-IN)
250
200
150
100
50
0
-50
-100
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)
RUN #7

TT17

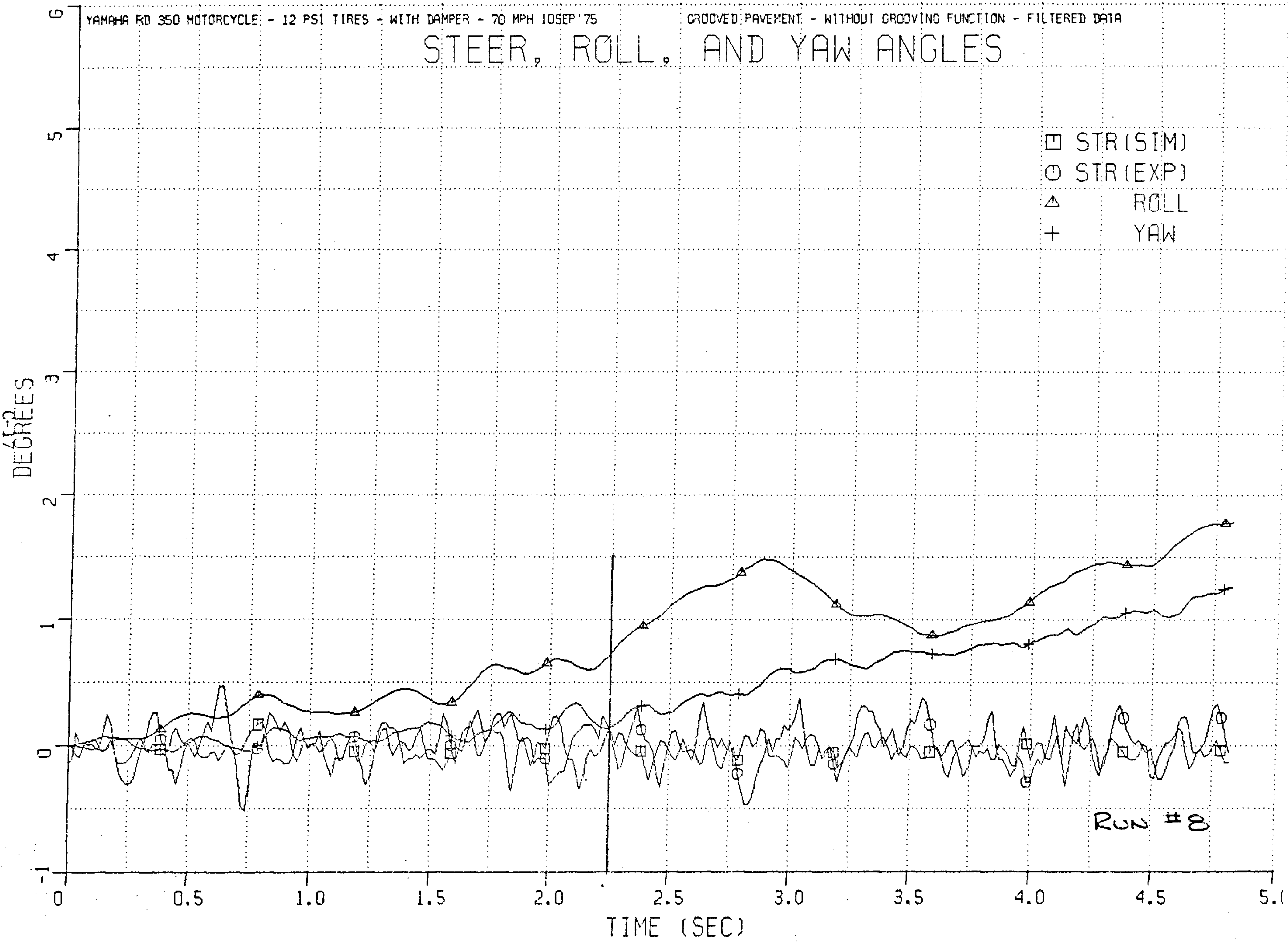

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 5SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, ROLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
C-15
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME (SEC)

RUN #7

TT18

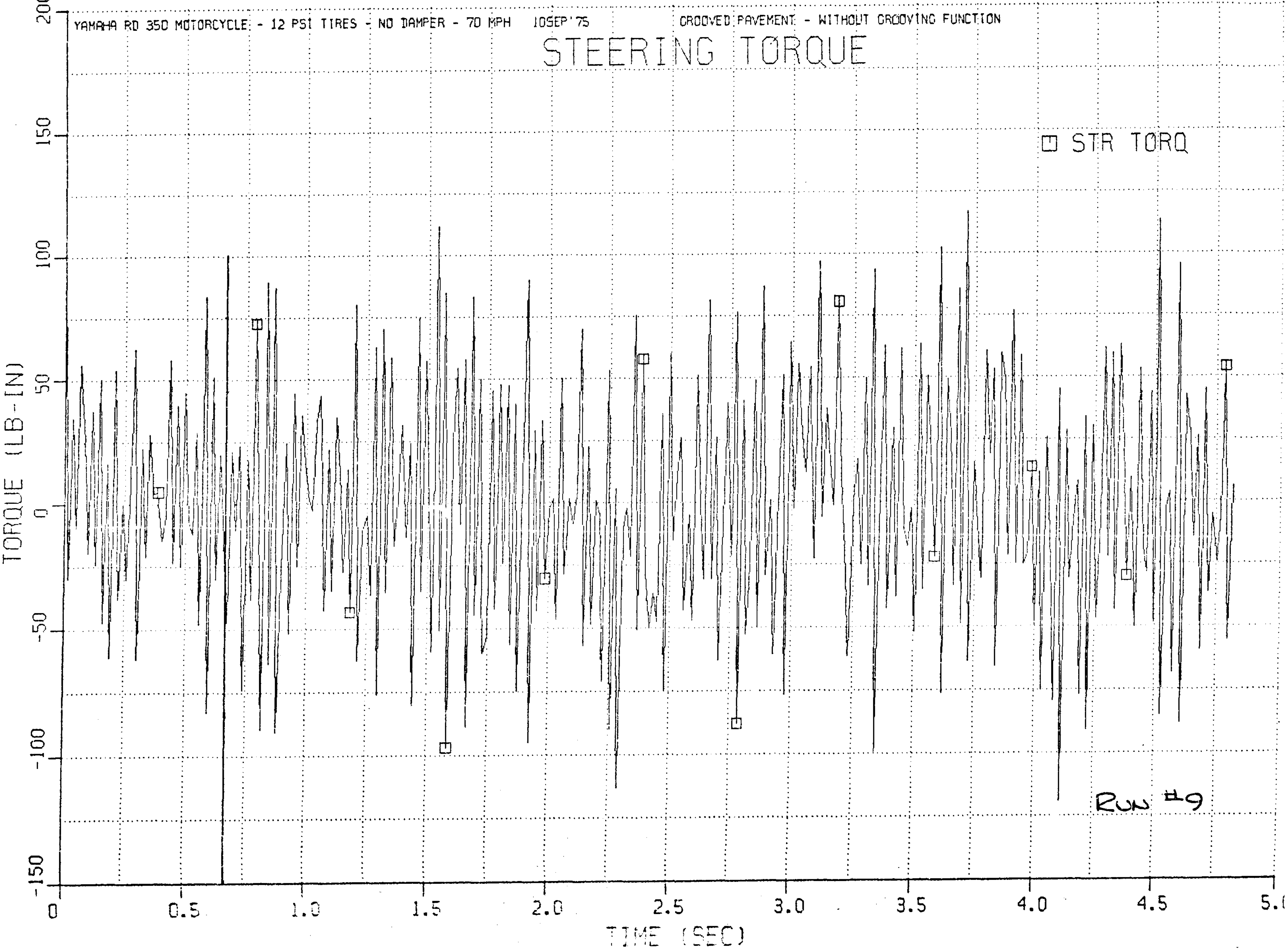

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 10SEP'75
GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION - FILTERED DATA
STEERING TØRQUE
☐ STR TORQ
TORQUE (LB-IN)
250
200
150
100
50
0
-50
-100
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)
Run #8

TT19


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 10SEP'75
GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION - FILTERED DATA
STEER, ROLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

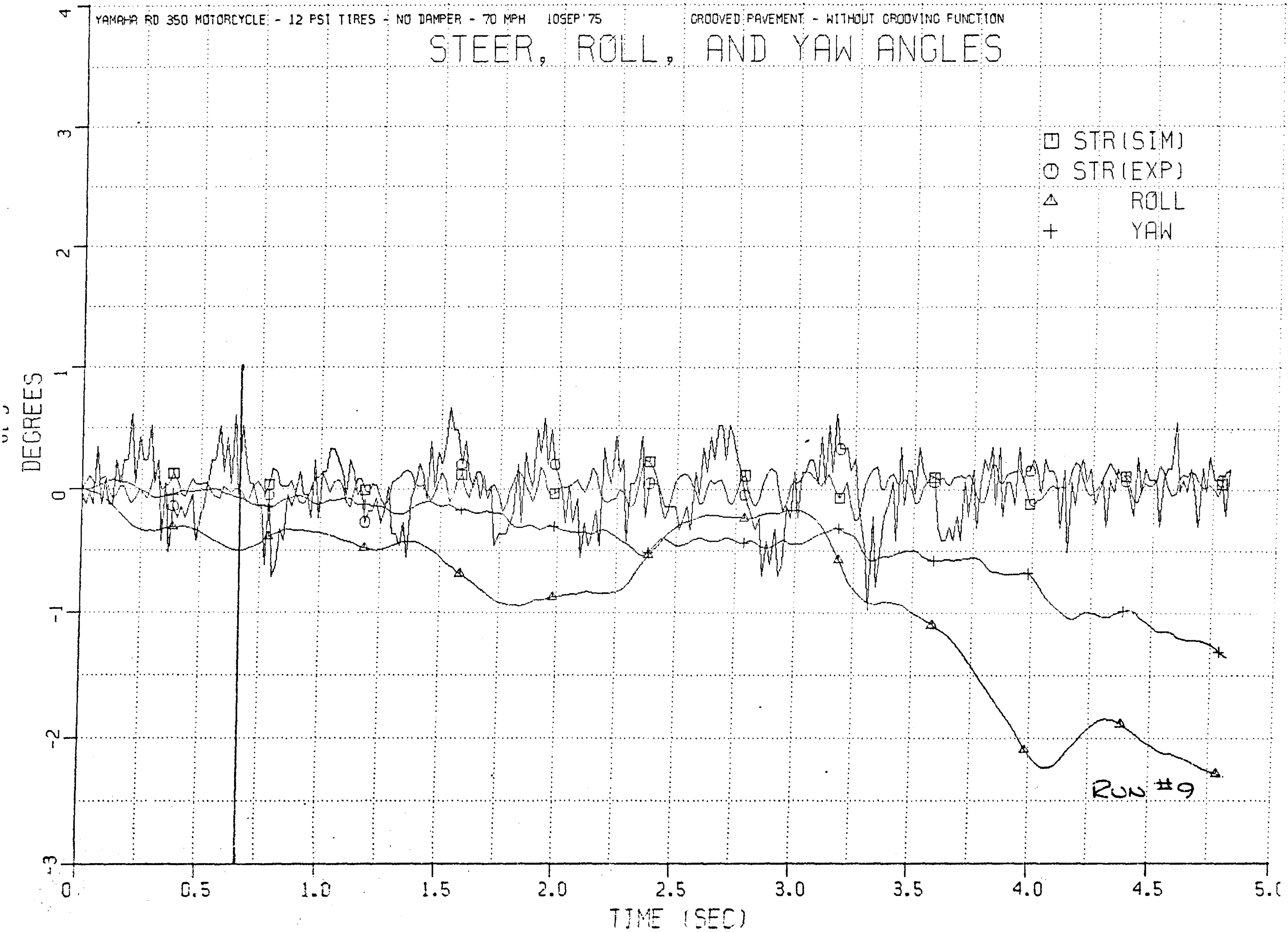
Run #8

TT19


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 10SEP'75
GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION
STEERING TØRQUE
☐ STR TORQ
TORQUE (LB-IN)
200
150
100
50
0
-50
-100
-150
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

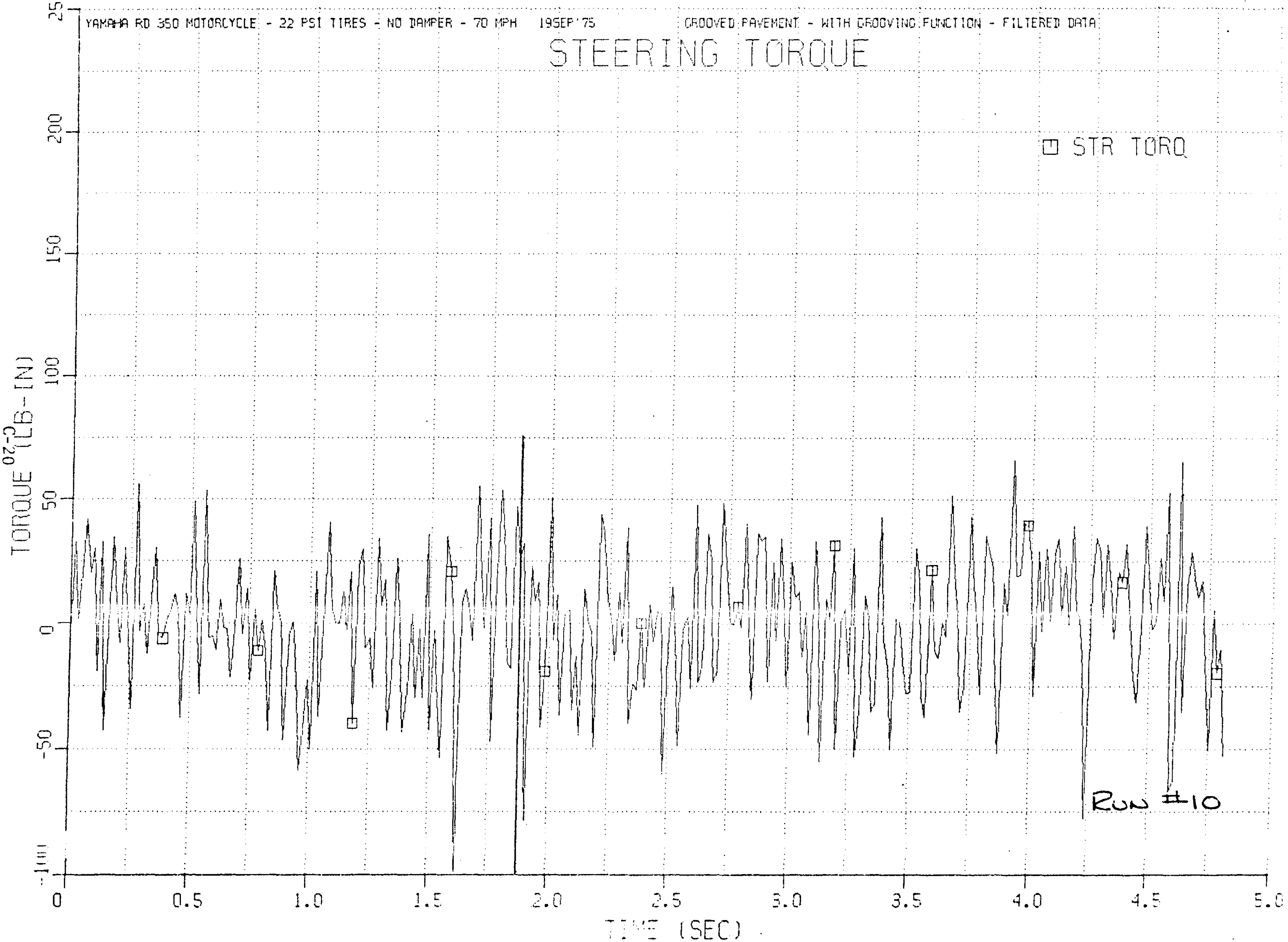
Run #9

TT19


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 10SEP'75
GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION
STEER, RØLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ RØLL
+ YAW
DEGREES
4
3
2
1
0
-1
-2
-3
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

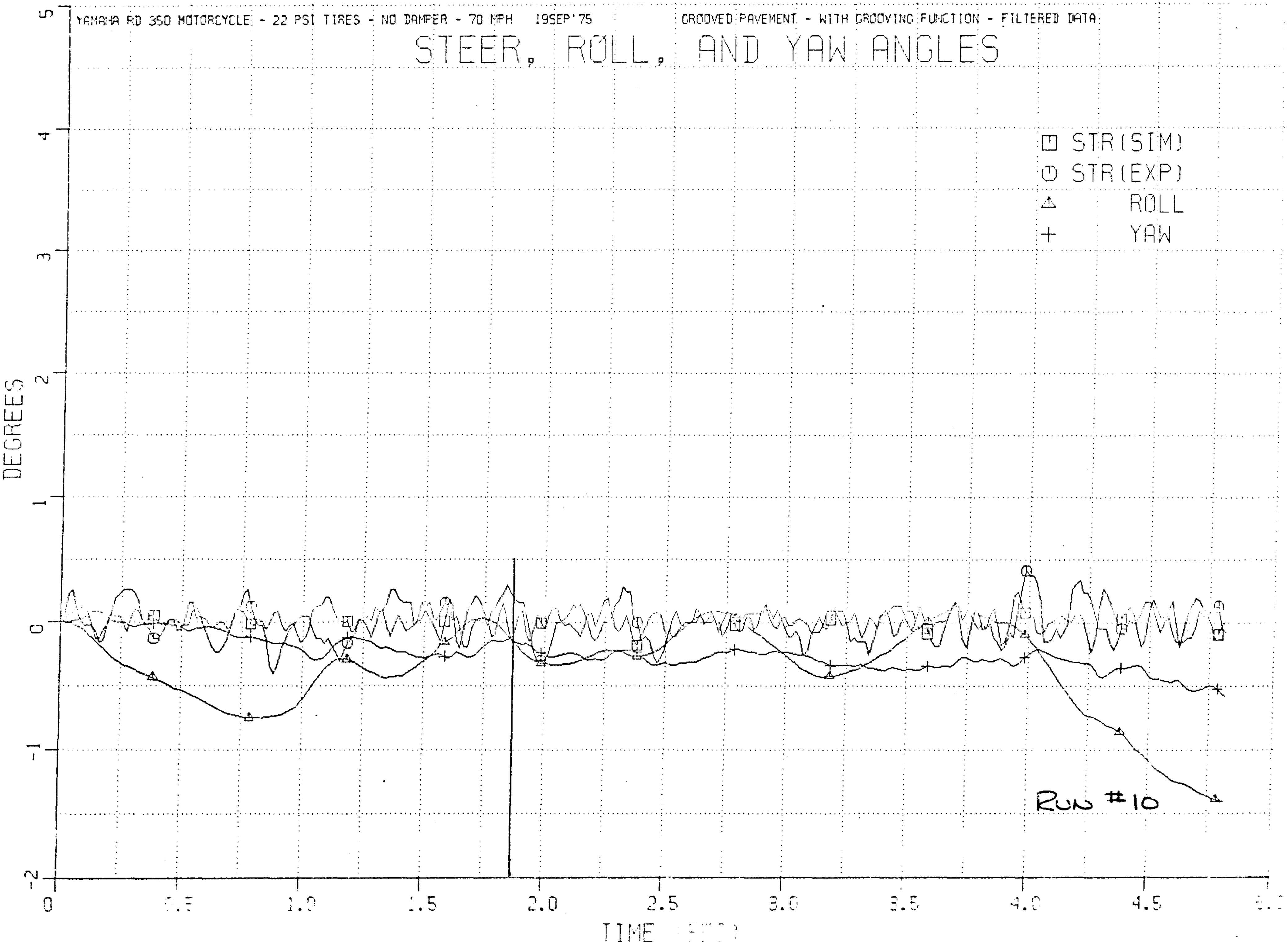
Run #9

TT10


YAMAHA RD 350 MOTORCYCLE - 22 PSI TIRES - NO DAMPER - 70 MPH 19SEP'75 GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA

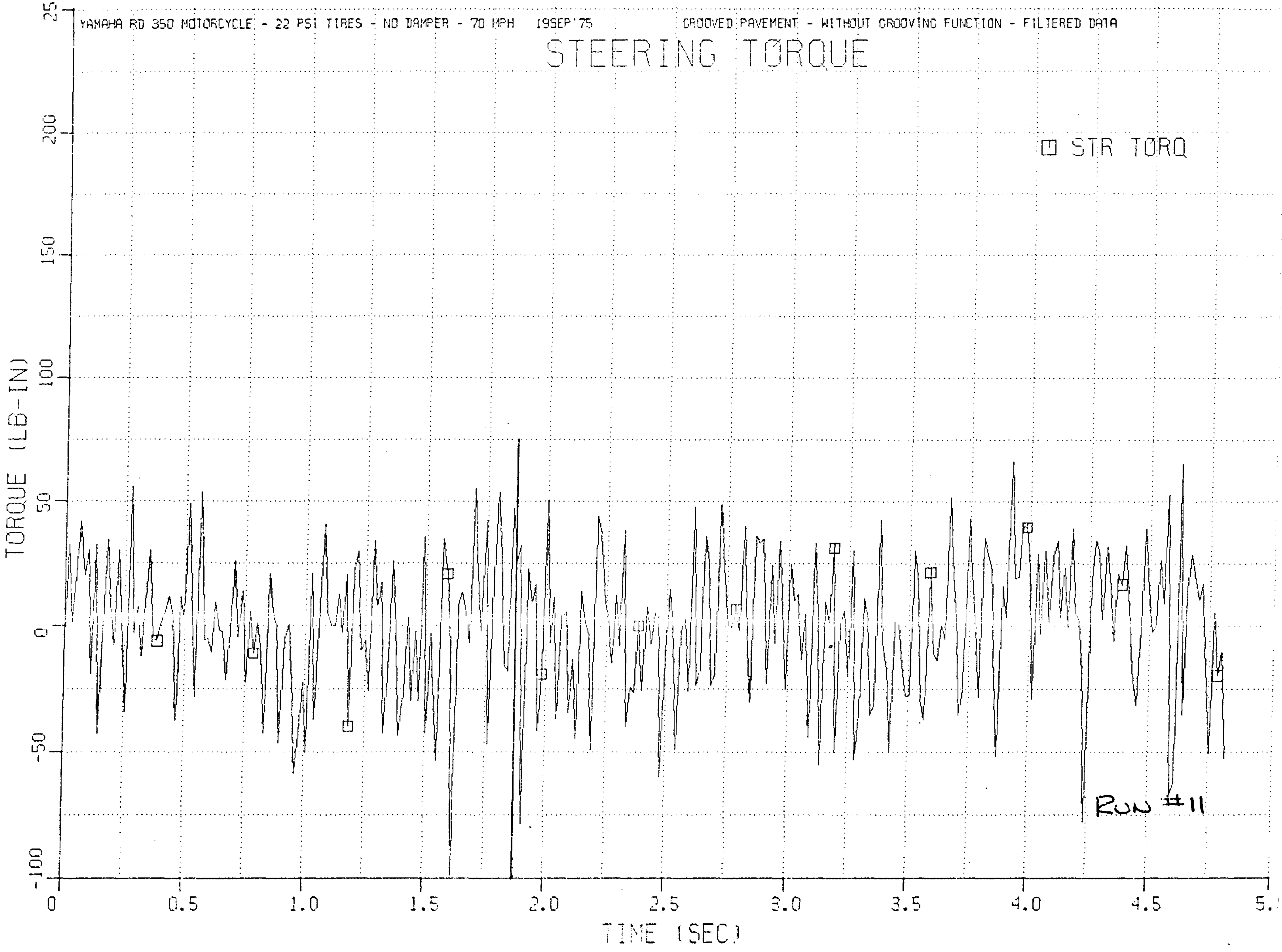
STEERING TORQUE

RUN #10

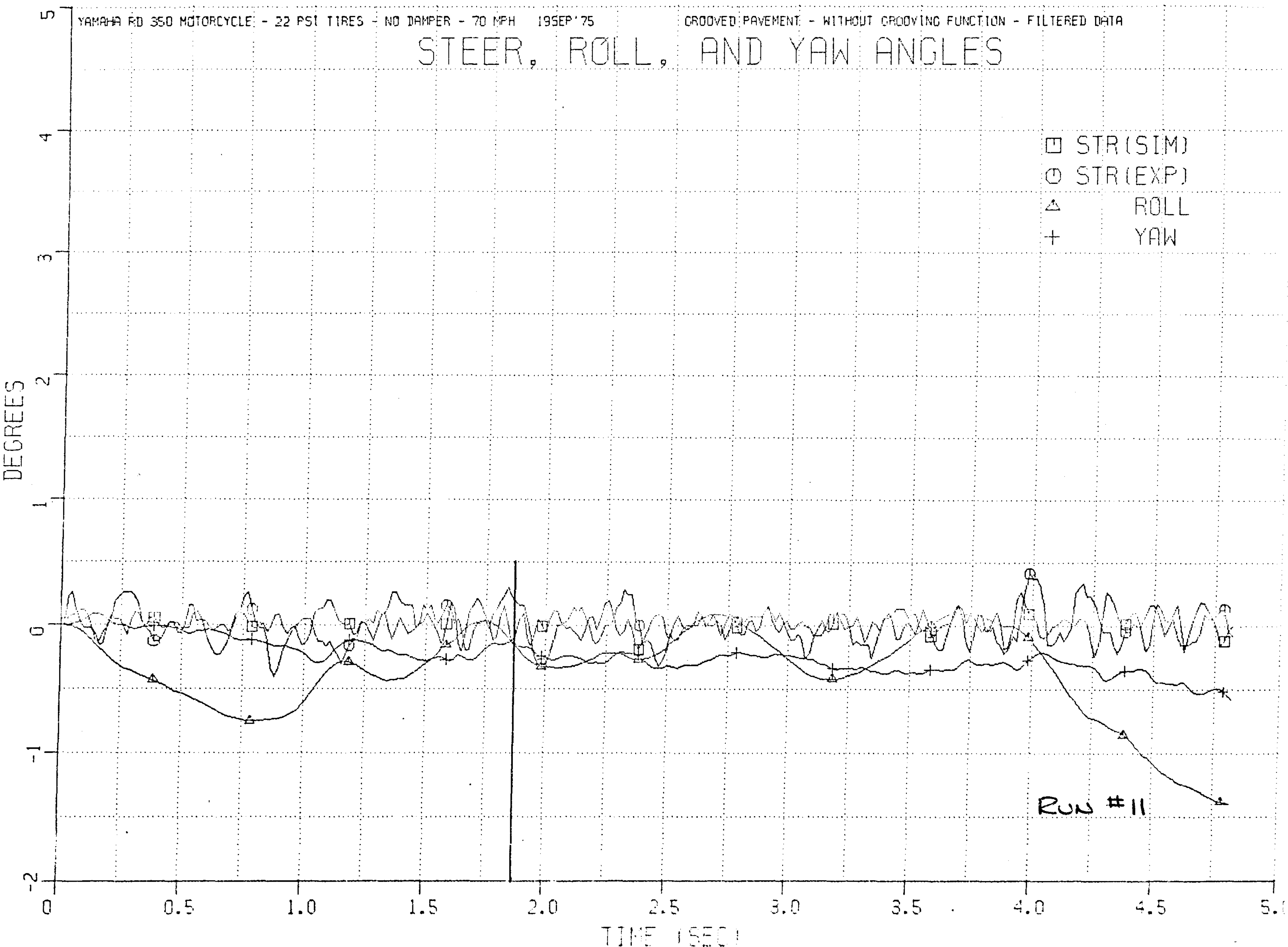

YAMAHA RD 350 MOTORCYCLE - 22 PSI TIRES - NO DAMPER - 70 MPH 19SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, ROLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
5
4
3
2
1
0
-1
-2
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME (SEC)

RUN #10

TT11


YAMAHA RD 350 MOTORCYCLE - 22 PSI TIRES - NO DAMPER - 70 MPH 19SEP'75 GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION - FILTERED DATA
STEERING TØRQUE
STR TØRQ
TORQUE (LB-IN)
250
200
150
100
50
0
-50
-100
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.
RUN #11

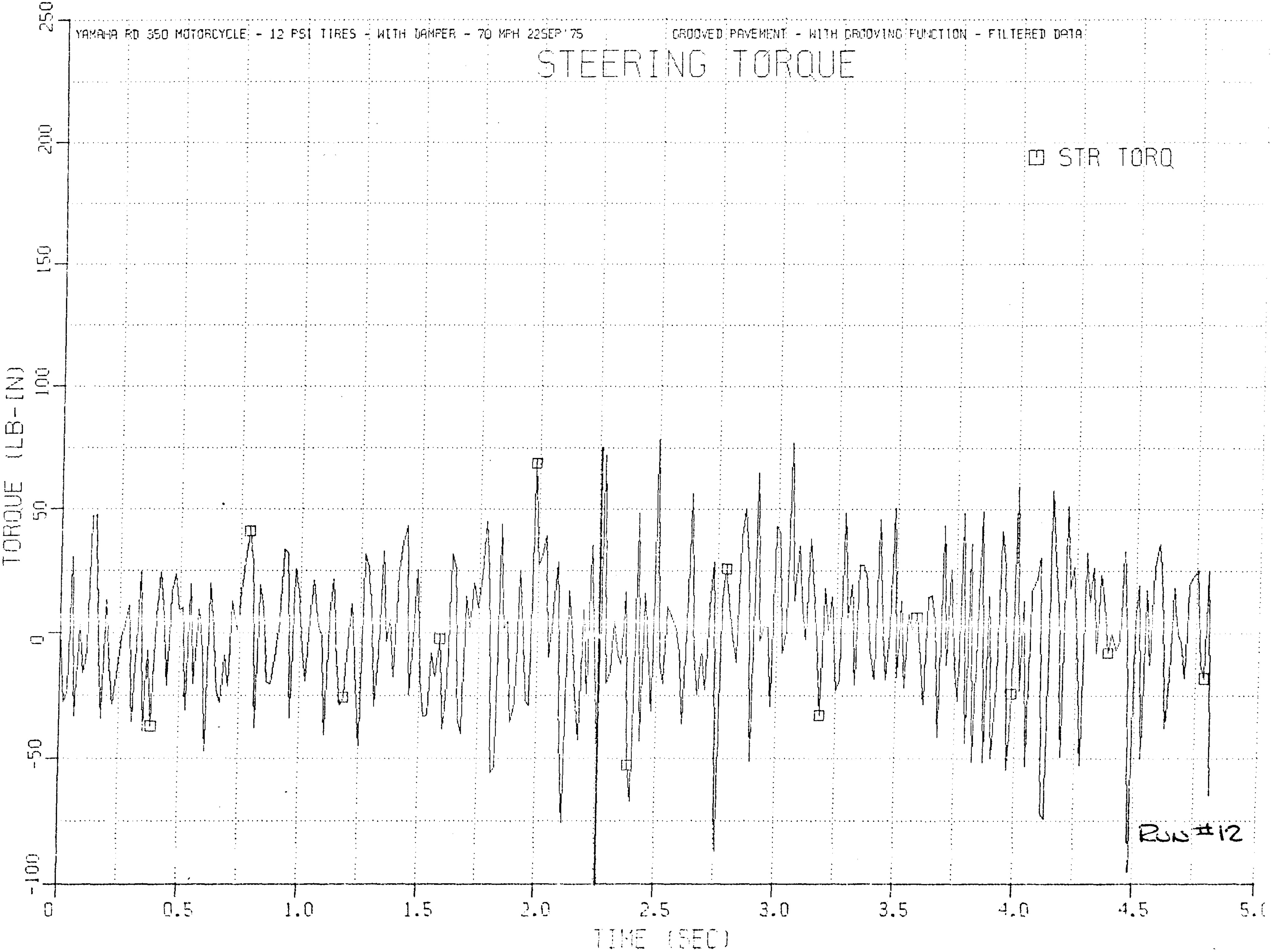
TT11



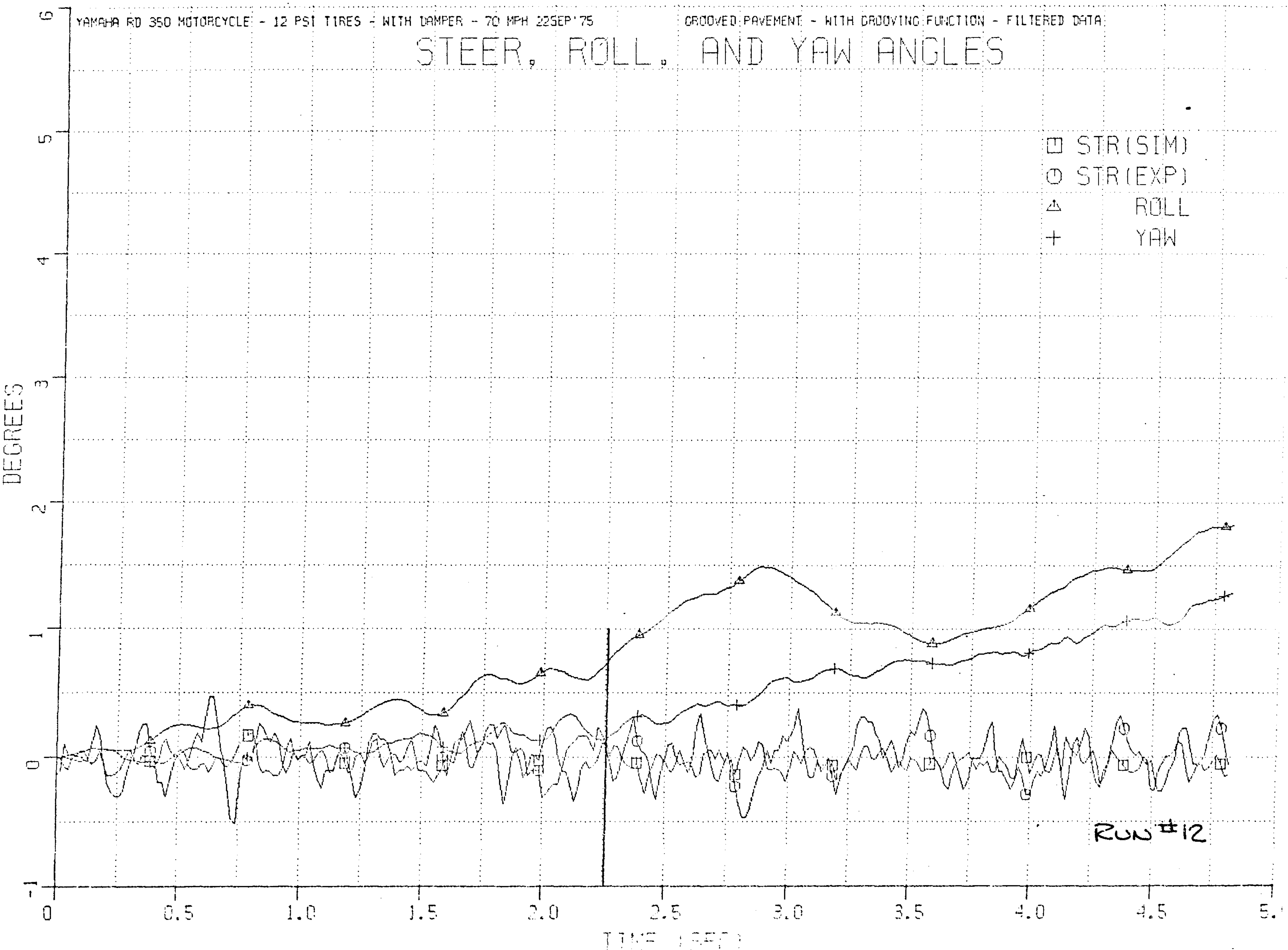
YAMAHA RD 350 MOTORCYCLE - 22 PSI TIRES - NO DAMPER - 70 MPH 19SEP'75
GROOVED PAVEMENT - WITHOUT GROOVING FUNCTION - FILTERED DATA
STEER, RØLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
5
4
3
2
1
0
-1
-2
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

RUN #11

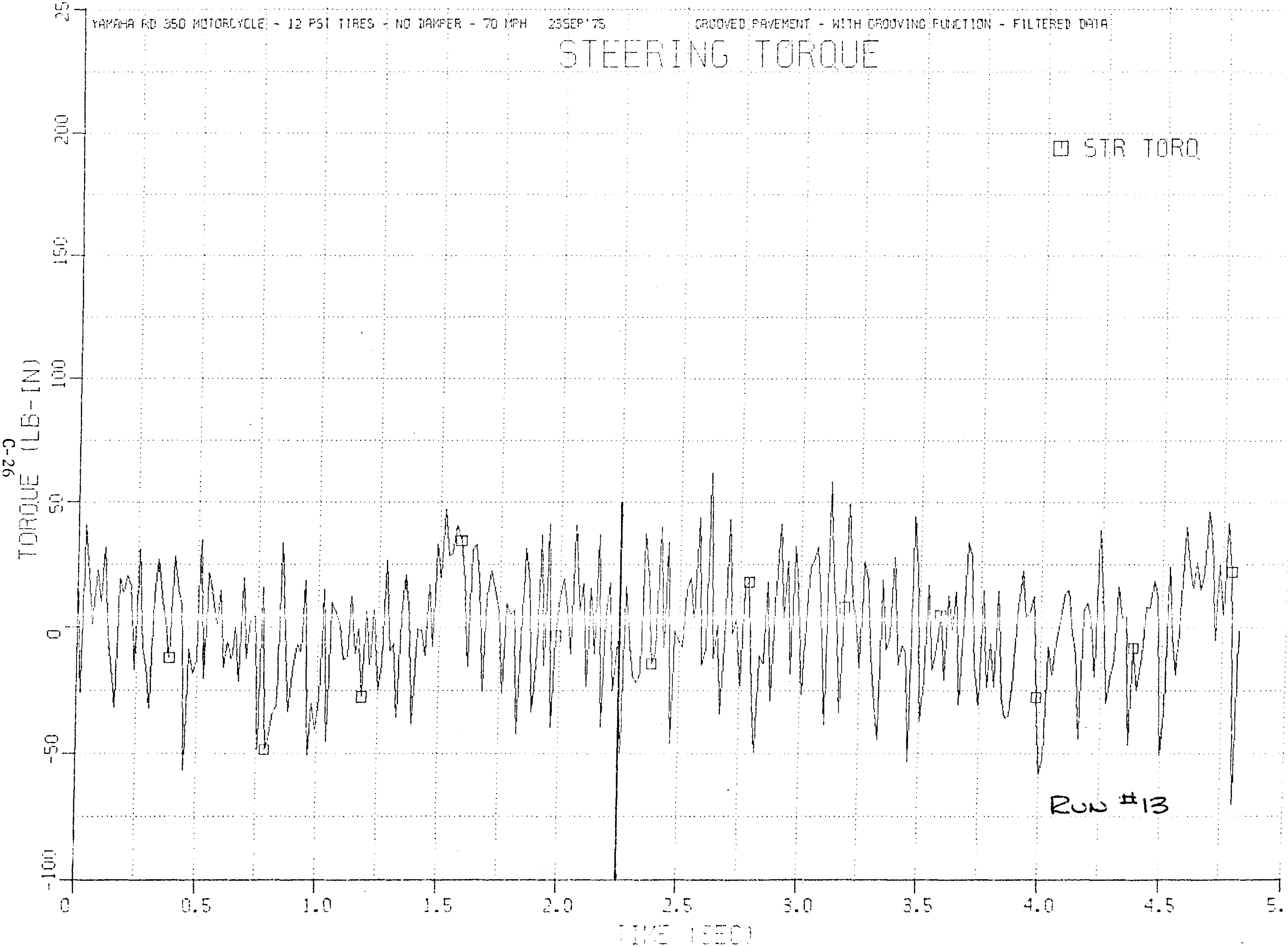
TT12


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 22SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEERING TØRQUE
STR TORQ
Run #12
TORQUE (LB-IN)
250
200
150
100
50
0
-50
-100
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.

TT12

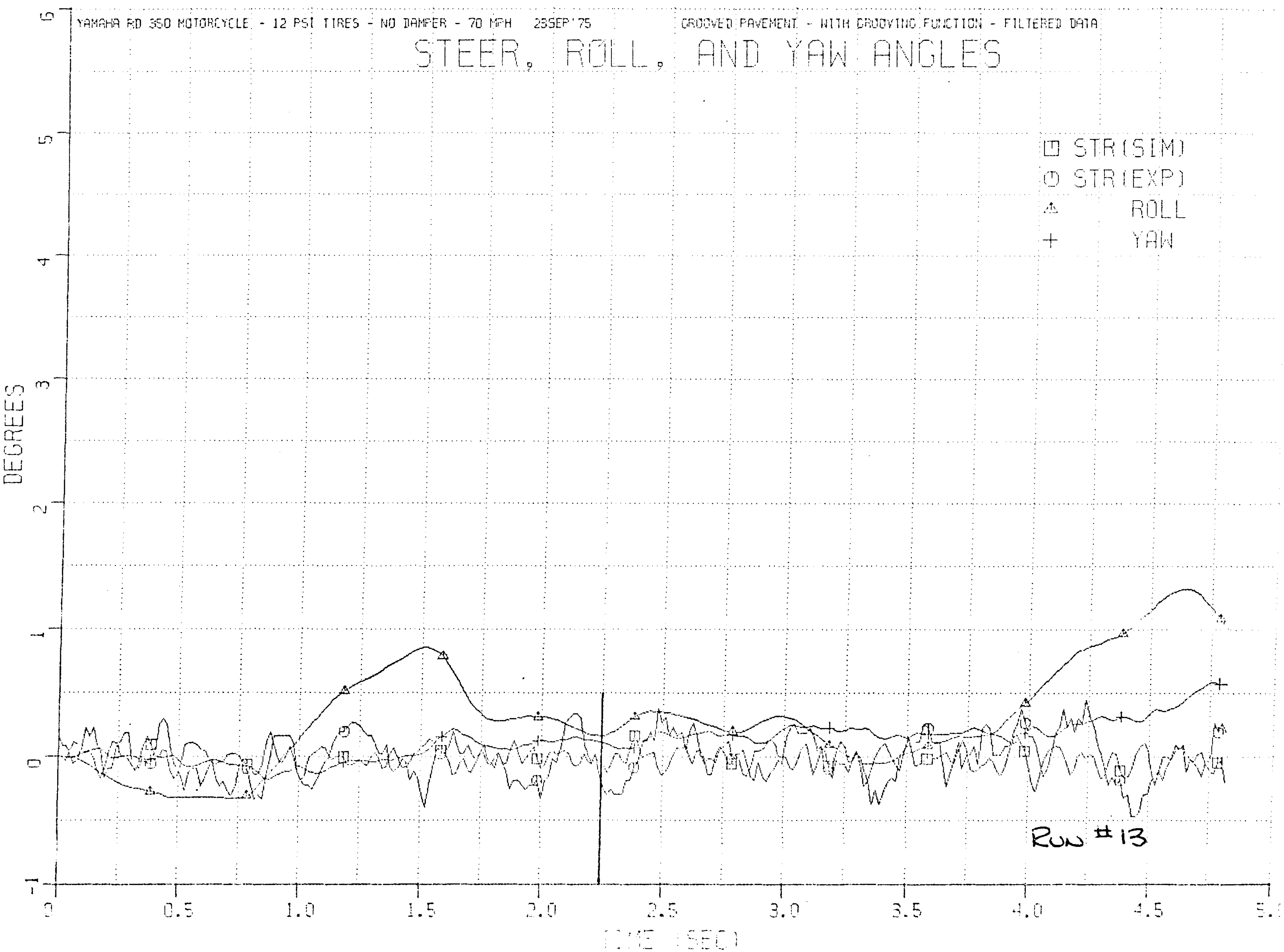

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - WITH DAMPER - 70 MPH 22SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, ROLL, AND YAW ANGLES
STR(SIM)
STR(EXP)
ROLL
YAW
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.
TIME (SEC)
RUN #12

TT13


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH   23SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEERING TORQUE
STR TORQ
TORQUE (LB-IN)
250
200
150
100
50
0
-50
-100
TIME (SEC)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

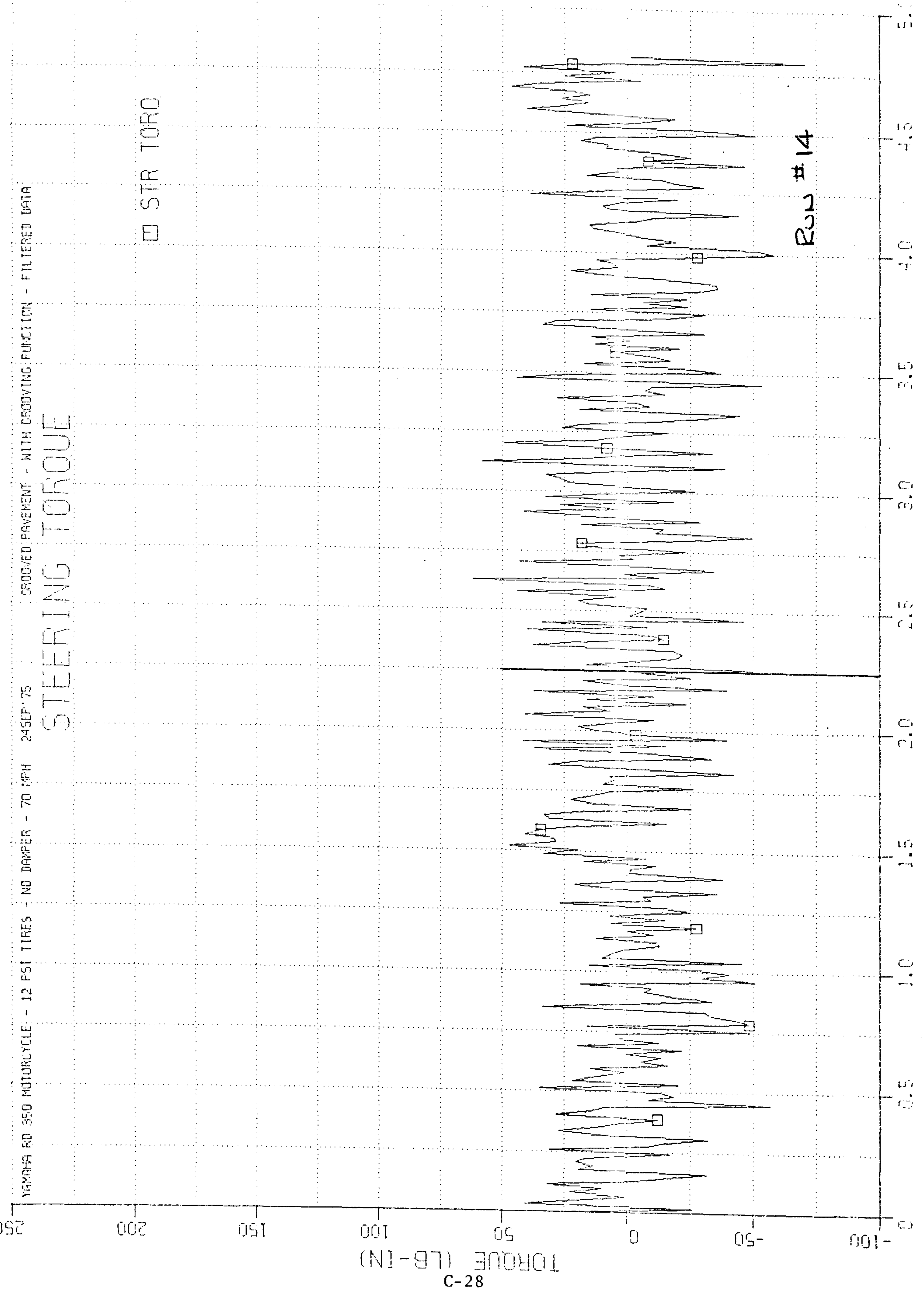
Run #13

TT13

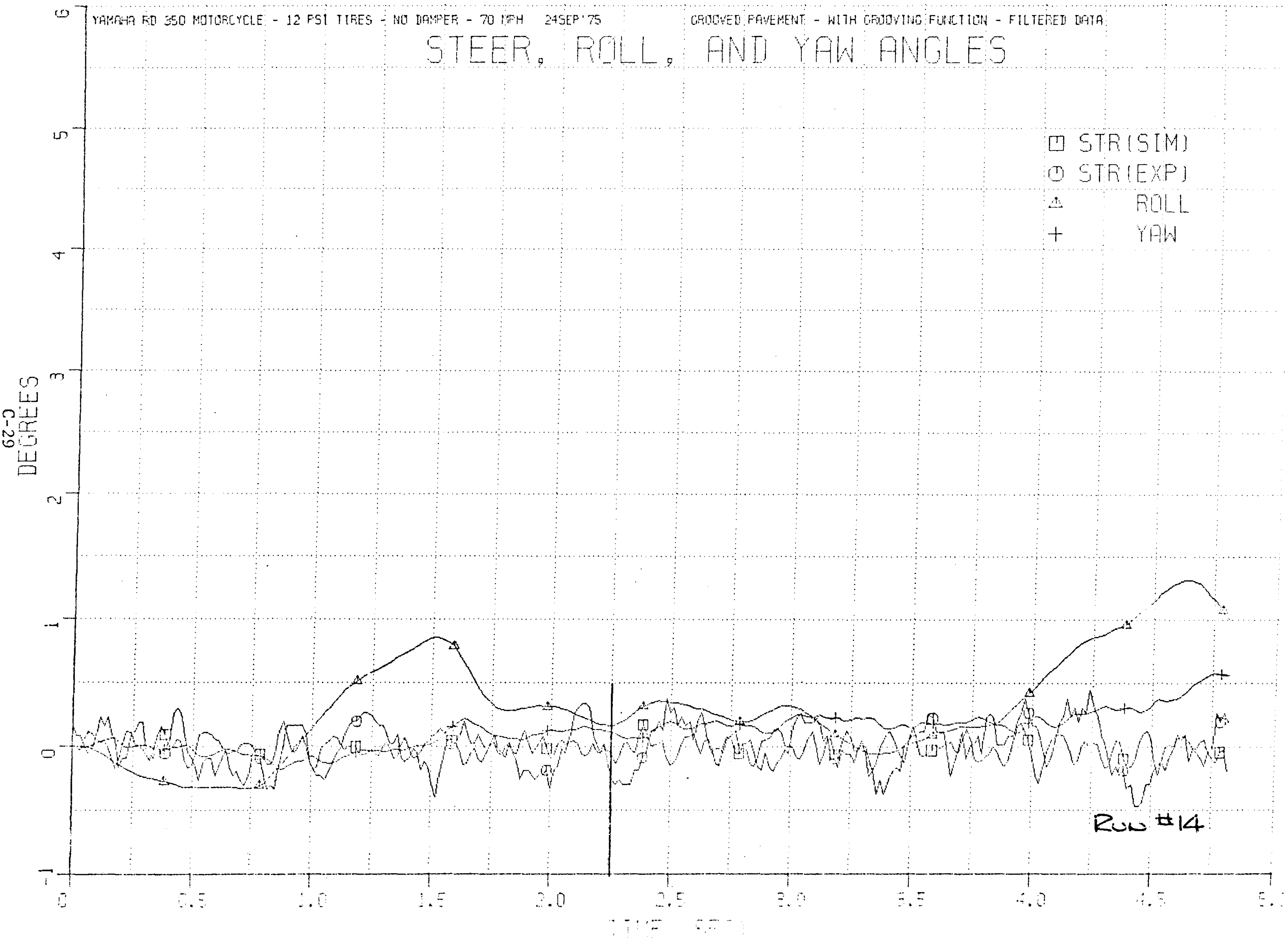

YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 25SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, RØLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ RØLL
+ YAW
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

Run #13

TT14


YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 24SEP'75 GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEERING TORQUE
□ STR TORQ
Run #14
250
200
150
100
50
0
-50
-100
TORQUE (LB-IN)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)

TT14



YAMAHA RD 350 MOTORCYCLE - 12 PSI TIRES - NO DAMPER - 70 MPH 24SEP'75
GROOVED PAVEMENT - WITH GROOVING FUNCTION - FILTERED DATA
STEER, ROLL, AND YAW ANGLES
□ STR(SIM)
○ STR(EXP)
△ ROLL
+ YAW
DEGREES
6
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
TIME (SEC)
Run #14