# 科技部補助專題研究計畫成果報告

（■期中進度報告/□期末報告）

## 以羅伯諾夫分數階運算元(Rabotnov's fractional operators)
## 探討混凝土結構物承受撞擊時之動態行為
## (Application of Rabotnov's fractional operators for the description of dynamic behavior of concrete structures during impact)

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本計畫除繳交成果報告外，另含下列出國報告，共 1 份：

□執行國際合作與移地研究心得報告

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中　　華　　民　　國 104 年 10 月 28 日

***Ministry of Science and Technology (MST), of Taiwan*** ***Russian Foundation for Basic Research (RFBR), Russia***

# Joint Research Cooperation

☐ Final
■ Progress
**Report**

Project Title：Application of Rabotnov's fractional operators for the description of behavior of concrete structures during impact

Project Period： (2014/01/01~ 2016/12/31) (total)
(2015/01/01~ 2015/12/31) (current)

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# Abstract

The main goal of this project is to model the behavior of concrete structural elements subjected to impact external loads via fractional calculus viscoelastic models. In this year, more advanced experimental equipments have been purchased and used for the experimental purposes. Namely, an accelerometer PCB 352C33 (frequency range 0.5-10000 Hz, sensitivity 102 mV/g), data acquisition system AD-LINK, Visual Signal software for data analysis, and RFDA MF basic to measure internal friction, Young's modulus, shear modulus and Poisson's ratio of concrete. Timoshenko type concrete beams (100×100×1000 mm) were tested for the impact response with a steel ball. Two methods to obtain fractional parameter have been undertaken. The first method includes the direct measurement of internal friction of concrete samples (prisms 250×120×60 mm) with subsequent calculation of the fractional parameter. Another method related to solution of integro-differential equation, obtaining fractional parameter using the data from ball dropping test. At the same time the analytical solution for the problem of contact interaction between vicsoelastic Timoshenko beam and elastic impactor was generalized for the case when a long elastic prismatic rod falling on a viscoelastic beam resulting in changes of its microstructure in the contact domain is considered. This approach was reported on a conference and a corresponding paper was published in an international scientific journal.

Key words:
mortar beam specimen, aging of concrete, dynamic viscoelasticity, fractional operators, impact loading, nondestructive testing, acceleration

# 摘要

本研究計畫主要目標為藉由分數積分黏彈性模式模擬混凝土結構構件承受撞擊力後之反應，今年中，本研究計畫已購買多項新進試驗設備並在試驗中使用，包括 PCB 352C33 加速規(頻率範圍 0.5~10000 Hz, 靈敏度 102 mV/g)、資料擷取系統(AD-LINK)、Visual Signal 電腦軟體分析試驗數據， RFDA MF 儀器量測混凝土材料內部摩擦力、楊氏模數、剪力模數及卜松比，以鋼珠球檢測 Timoshenko 形式混凝土(100×100×1000 mm)之撞擊反應，使用兩種方法計算分數參量(fractional parameter)，第一種方法包括直接混凝土塊體(250×120×60 mm)後緊接著計算分數參量，第二種方法則由鋼球落擊試驗數據利用積-微分方程式(Integro-differential equation)求解，當考量一長形彈性等截面桿(prismatic rod)落擊黏彈性樑，造成撞擊區微結構改變之情形，同時也將黏彈性 Timoshenko 樑與彈性撞擊物間接觸區交互作用問題之解析解予以廣義化，此模式之研究成果已發表在國際期刊論文及國際研討會論。



關鍵字:

砂漿梁試體、混凝土齡期變化、動黏彈性力學、分數運算元、撞擊載重、非破壞性檢測、加速度

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# Chapter 1 Introduction

The problems associated with impact interaction of thin bodies (rods, beams, plates, shells) with other bodies, are widely used in various fields of science and technology. Since these tasks are related to the problems of dynamic contact interaction, the solution involves considerable mathematical and computational difficulties. In order to overcome those difficulties many different methods reviewed in [1, 2] have been proposed.

In the last three decades the use of fractional calculus has attracted considerable interest in various fields of natural sciences and technology. Article [3] reviews a thorough analysis of the application of fractional calculus to the dynamical problems of linear and non-linear genetic continuum mechanics and structures, including the problems of shock interaction.

In this report, the analytical approach was proposed by the authors to analyze the dynamic behavior of Timoshenko isotropic elastic beam impact long elastic rod [2,4], and was generalized to the case of shock interaction of elastic prismatic long rod of rectangular cross section with hereditary elastic beam type of Timoshenko. Viscoelastic properties of Timoshenko isotropic elastic beam outside the area of contact interactions are described in the standard linear solid model with conventional derivatives of integer order. Viscoelastic properties inside the contact area are described in the standard linear solid model with fractional derivatives. A fact that a failure occurs during the impact of crosslinks between molecules of the material of the beam being the contact area leads to more free motion of molecules in relation to each other and consequently reduces the viscosity in the contact area. The fractional variation parameter can be controlled by the viscosity of material of beams.

# Chapter 2 Theoretical Background

**Problem formulation**

Let a long prismatic elastic rod of rectangular cross-section with dimensions $2\tau_{im}$ and $a$ move along the axis $z$ with velocity $V_0$ toward an isotropic rectangular Timoshenko's beam of infinite length (Fig. 1). The last assumption takes place because of the short impact interaction time for not considering reflected waves.

Impact occurs at the moment *t=0* in the origin of the coordinates system *x, y, z*. At the moment of impact, impact waves for both of the rod and the beam initiate, which later propagate along the impactor and the target with velocities of transient waves.

Dynamic behavior of viscoelastic beam with consideration of rotary inertia and in-plane shear deformations can be described by the following system of equations:

$$\frac{\partial Q}{\partial z} = \rho A \dot{W}, \quad \dot{Q} = K\mu_{\infty} A\left[\varphi - \frac{v_{\mu}^{\varepsilon}}{\tau_{\mu}^{\varepsilon}}\int_0^t e^{-(t-t')/\tau_{\mu}^{\varepsilon}}\varphi(t')dt'\right], \tag{1}$$

$$\frac{\partial M}{\partial z} - Q = -\rho I \dot{\beta}, \qquad \dot{M} = -E_{\infty} I\left[\frac{\partial \beta}{\partial z} - \frac{v_E^{\varepsilon}}{\tau_E^{\varepsilon}}\int_0^t e^{-(t-t')/\tau_E^{\varepsilon}}\frac{\partial \beta(t')}{\partial z}dt'\right], \tag{2}$$

where M – bending moment, Q – lateral force, $W = \dot{w}$ - deflection rate for the points of the middle plane, $\beta$ - rotation angle around z-axis of the cross-section, $\varphi = \partial w / \partial z - \beta$, $v_E^{\varepsilon}$, $v_{\mu}^{\varepsilon}$, $\tau_E^{\varepsilon}$ and $\tau_{\mu}^{\varepsilon}$ are the material constants, $E_{\infty}$ and $\mu_{\infty}$ are non-relaxed values of Elastic modulus and Shear modulus, correspondingly, $\rho$ - beam material density, K – shear coefficient, A and I are cross-section area and moment of inertia respectively, and the dot above denotes time derivative.

It is necessary to add equations describing dynamic behavior of the impactor to the equations (1) and (2):

$$\frac{\partial \sigma}{\partial z} = \rho_{im}\dot{v}, \quad \dot{\sigma} = E_{im}\frac{\partial v}{\partial z}, \tag{3}$$

where $\sigma$ - stress, $v$ - velocity, $\rho_{im}$ and $E_{im}$ - impactor's material density and Young's modulus, respectively. Also, the equation of motion for the contact area $2\tau_{im}$ in length as well as equation for the contact force $F_{cont}$ [5] must be added (Fig. 1):

$$2\tau_{im}A\rho\ddot{w} = 2Q\Big|_{z=\tau_{im}} + F_{cont}, \tag{4}$$

$$F_{cont} = E_{\infty}(\alpha - w) - \Delta E t\int_0^t \mathrm{Э}_y\left(-\frac{t-t'}{\tau_{\varepsilon}}\right)\left[\alpha(t') - \mathrm{w(t')}\right]dt', \tag{5}$$

where $\alpha$ and $w$ - displacements of upper and lower ends of the spring, respectively, displacement $w$ equals to the beam displacement at the contact point (Fig. 1), $\tau_{\varepsilon}$ - relaxation time, $\Delta E = E_{\infty} - E_0$ - defect modulus, $E_0$ - relaxed Yong's modulus, $\gamma (0 < \gamma \le 1)$ - fractional parameter,

$$Э_y\left(-\frac{t}{\tau_\varepsilon}\right)=\frac{t^{\gamma-1}}{\tau_\varepsilon^\gamma}\sum_{n=0}^{\infty}\frac{(-1)^n(t/\tau_\varepsilon)^{\gamma n}}{\Gamma\left[\gamma(n+1)\right]} \quad (6)$$

- Rabotnov's fractional exponential function [6], and $\Gamma(y)$ - gamma-function. Equation (6) equivalent to the standard linear solid model with fractional derivatives [3].

There is a need to add initial conditions to the system of equations:

$$\alpha\big|_{t=0}=w\big|_{t=0}=\dot{w}\big|_{t=0}=0,\quad \dot{\alpha}\big|_{t=0}=V_0\,. \quad (7)$$

**Solution method**

For the solution of this problem there are two methods can be used: ray method and Laplace transformation. Ray method is applicable for the construction of an approximate solution for the beam on the area from the shock wave till the border of contact area, as well as definition of exact solution in excited area of the elastic rod. Within the contact area for the contact force definition Laplace transformation is used.

In order to find solution out of the contact zone in both, the beam and the rod, compatibility condition [7]:

$$\dot{Z}=-G\frac{\partial Z}{\partial z}+\frac{\delta Z}{\delta t} \quad (8)$$

and polynomial ray expansion for the unknown functions Z, where G – normal velocity of the wave surface and $\delta Z/\delta t$ - $\delta$-time-derivative [2, 4]. From the results the following expressions for the lateral force on the border of the contact zone and contact stress in the end of the rod are obtained:

$$Q=-\rho AG_\infty W, \quad (9)$$

$$\sigma_{cont}=\rho_{im}G_{im}(V_0-W-\dot{\alpha}), \quad (10)$$

where $G_\infty=\sqrt{K\mu_\infty/\rho}$ and $G_{im}=\sqrt{E_{im}/\rho_{im}}$ - propagation velocities of quasi-transverse shock wave and longitudinal shock wave in the rod, respectively. When the contact stress (10) is known, contact force can be found as:

$$F_{cont}=b(V_0-W-\dot{\alpha}), \quad (11)$$

where $b=2a\tau_{im}\rho_{im}G_{im}$.

Equations (5), (11) and (4) rewritten according to (9) in the following form

$$M\ddot{w}+MB\dot{w}=F_{cont}, \quad (12)$$

where $B=G_\infty/\tau_{im}$, and $M=2\tau_{im}A\rho$ - mass of the contact area, represent closed system of equations with three unknowns: $F_{cont}, w, \alpha$.

Applying Laplace transformation to the system of equations (5), (11) and (12), and switching from the images to originals, using calculus of residues and the first list of Ryman's surface, the contact force can be found as

$$F_{cont}(t) = \int_0^{\infty} B(s)(1-e^{-st})ds + \frac{A}{\sqrt{k^2+\omega^2}}\left[\sin(\phi+\phi_0) - e^{-kt}\sin(\omega t+\phi+\phi_0)\right], \qquad (13)$$

where $-k \pm i\omega$ - simple poles at the first list of Riemann's surface, $tg\phi_0 = \omega / k$, and functions B(s), A and $\phi$ are not shown due to their bulkiness.

The first term in the expression (13) defines the drift of equilibrium position, and the second one – damped vibrations around drifting equilibrium position.

Dependence of dimensionless contact force $F_{cont}^* = F_{cont}\sqrt{k^2+\omega^2} / A$ on dimensionless time $t^* = \omega t$ is shown on Fig. 2 for different values of the fractional parameter, whose values are shown in digits near corresponding curves. Values $\gamma = 0$ and $\gamma = 1$ correspond to an elastic Timoshenko beam and viscoelastic Timoshenko beam, whose properties can be described by the standard linear solid model with regular viscosity. From Fig. 2 it is obvious that the reduction of fractional parameter leads to reduction of both the maximum contact force and contact time.

# Chapter 3 Equipment comparison and description of the selected device

Experimental registration of internal friction changes as well as fractional parameter γ requires special equipment. There are many kinds of devices that can be used for this purpose. It is necessary to select the most proper device within the budget. The following devices were considering for the experimental program:

- DTM-II-H Dynamic Elastic Modulus Damping Internal Friction Analyzer, Hunan Zhenhua Analysis Instrument Co. Ltd, China
- Yong's Modulus and Damping Meter IE-RT, Nippon Techno-Plus Co., Ltd, Japan
- RFDAbasic, IMCE, Belgium
- RFDA professional, IMCE, Belgium

TW team has made the analytical comparison of several devices and finally RFDA FM basic was selected as the best and the most economical option. The main comparison for all kinds of equipment was summarized in Table 1.

The Resonant Frequency and Damping Analyzer (RFDA) is a non-destructive testing device to determine the resonant frequencies of materials. The added value of the RFDA lies in the analysis of the **damping** for each **resonant frequency**. It is well known that the elastic properties of a test specimen are related to its mechanical resonance frequency. The damping or Q-factor represents the energy absorption by the material. The RFDA analyses the vibration induced by a mechanical impulse. The essentially non-destructive method can be applied at different circumstances such as high temperatures, low temperatures, controlled humidity, ... It is also possible to perform the test on the same test specimen between different thermal shock cycles, determinate the influence of aging, ... While measuring several specimens, it is important to avoid external extraneous vibrations without restricting the desired mode of specimen vibration. The measuring procedure is controlled by the RFDA basic software [8].

A vibration is induced by a small mechanical impulse. The energy is dissipated by the material into a vibration. This vibration has a frequency spectrum according to its resonant frequencies which are depending on the elastic properties of the material, the geometry and the density [8].

Each frequency is associated with a specific damp according to the energy absorption of the material. The exact microstructural origin of damping, or internal friction or mechanical loss varies from one class of materials to the other. The vibration is detected by a transducer. The transducer produces an electrical signal which is sent to the computer where the signal will be analyzed. The specially developed mathematical algorithm calculates each frequency and damping from the detected frequency spectrum assigning to each frequency a sinusoidal, damped vibration of the form as it is shown on the Fig. 3.

$$x(t) = Ae^{-kt}\sin(\omega t + \varphi) \quad (14)$$

For each ω the corresponding frequency *f* is calculated as:

$$f = \omega / 2\pi \tag{15}$$

The vibration of a specimen can also be analyzed from the damping point of view. The mechanism of damping or internal friction can be understood as the rearrangement of defects in the crystal structure of the material. Due to the applied stress these dislocations and vacancies are forced to move to energetically more favorable positions. To start this mechanism an intermediate position of higher energy must be passed that is possible owing to the applied stress. Reaching this state of mechanical equilibrium the energy is dissipated into heat and sound, called damping or mechanical loss. The capacity of damping k is dependent of the dimensions of the specimen. The specific damping on the other hand is a material property defined as [8]:

$$Q^{-1} = \Delta W / 2\pi W \tag{16}$$

This mechanical loss is reflected in the measured vibration of the specimen and can be seen as the relative decrease of the signal:

$$Q^{-1} = 1/\pi \ln(x_1 / x_2) = \delta / \pi \tag{17}$$

where:
$x_1/x_2$ = ratio of the amplitude of the signal in one period T; δ = the logarithmic decrement.
From (16) and (14) the following equation:

$$Q^{-1} = kT / \pi = k / \pi f \tag{18}$$

can be derived [8]. By this way the damping, an important property in characterizing the material, is easily calculated from the measured damping and frequency. A special accelerometer with data acquisition system was purchased to conduct the impact test. The detailed description and technical characteristics of all the equipment are provided below.

Accelerometer PCB 352C33 with frequency range 0.5~10000 Hz and sensitivity 102 mV/g perfectly fits our research purposes. Data acquisition system AD-Link together with AnCAD, Inc., Visual Signal provide all the necessary set of functions to receive and analyze the signal obtained during the impact process.

# Chapter 4 Experimental details

The experimental program is separated into three parts (see Fig. 4). First of all, the concrete properties, such as slump of fresh concrete, compressive strength development, Young's modulus and Poisson's ratio, ultrasonic pulse velocity, etc., must be defined. For this purpose 18 pieces of concrete cylinders (200X100 mm) had been cast and tested at different ages. Slump test and cylindrical concrete specimens are shown on Fig. 5 and Fig. 6, respectively. Mix proportions were designed according to ACI standard and presented in Table 2.

Second, according to the original plan, an impact test must be conducted. There are 3 Timoshenko type concrete beams (100×100×1000 mm) that have been cast for the experiment (Fig. 7). Seven ages are assigned for the impact tests: 7, 14, 28, 56, 90, 180 days, and 1 year. In this year two more types of impactors were used for the test: two rectangular steel rods of square cross-section (19×19mm), 90 mm and 180 mm in length. All the specifications for every kind of impactor are shown in Table 3. Impact test allows to determine acceleration vs. time, after that contact force vs. time can be determined. When the contact force (a function of time) is known, solving an integro-differential equation, fractional parameter $\gamma$ can be obtained.

Third, there is another way to determine the fractional parameter. Concrete blocks (120×60×40 mm) from the same mix proportions were tested for the change of internal friction with time. When the internal friction for each single frequency is known, the Q^-1 vs. time dependence can be plotted, after that fractional parameter is calculated. However, to conduct such an experiment with real concrete samples a certain amount of preliminary work must be done. The problem is that the original RFDA basic device comes with a supporting aluminum frame with nylon wires, suitable for small samples (see Fig. 8). In order to test big concrete samples, TW team has designed and made another frame of stainless steel with steel wires, which allows to test big and heavy samples. The new supporting device is shown on Fig. 9. It has several adjustable positions for the wires and tightening bolts can control tension of the wires. By using such a device it becomes possible to test concrete blocks over 1 kg in mass.

After the fractional parameter is determined by these two methods, the comparison of results must be done.

# Chapter 5 Results and Discussion

Compressive strength results together with NDT results for mortar samples are shown on Table 4. As we can see from the experimental data table, compressive strength at the age of 3 days reached 36 MPa and 39 MPa at the age of 7 days. At the age of seven days we made sure that the concrete beams were strong enough for the impact test and they would not have any cracks after the impact. Dynamic elastic and shear moduli also had very high values. Density remained almost the same and ultrasonic wave velocity had increased with time. Plots of each parameter versus time are shown on Fig. 10 to Fig. 14, respectively.

Due to the bulkiness of the test results of beam specimens, only one particular result will be shown in the report. For example, test result for the beam 1 impacted by a steel ball (4 cm in diameter) at the age of 7 days is shown in Fig. 15. A single experimental program being able to define the contact time and contact force is one of the main aims of the ball dropping test. According to [9], contact time is semi-period of the first deflection of the beam. Since the signal obtained from the accelerometer represents the change of beam acceleration at the middle point with time, the first part of the deflection can be multiplied by the mass of the impactor with negative sign, and the contact force can be easily obtained from the experimental data. Practically, it can be observed on Fig. 16. As we can see from Fig. 16, contact time is very short, about 250 μs and the contact force can be easily approximated by a polynomial function of $3^{rd}$ order. Later, this function must be substituted into theoretical equation of contact force, and the fractional parameter must be found.

An experimental setup for the internal friction test is shown in Fig. 17. RFDA software has been used for the test. It is worthy to note that the experimental table for the test must be laid to a very horizontal position. Changes of internal friction and of the frequency with time are shown on Fig. 18 and Fig 19, respectively. As we can see from the figures, the frequency is increasing with time, however, the internal friction is decreasing. These phenomena can be explained by the progressive hardening of concrete and by the gradual reduction of its viscosity.

# Chapter 6 Conclusions

During this year, the project has a great progress. One of the hardest problems to identify internal friction of concrete has been solved. Moreover, the contact force and time during the ball impact have been obtained experimentally and an analytical approximation for the contact force as a function of time has been found. The analytical calculation of fractional parameter is under the progress. Fractional parameter will also be calculated from the internal friction test data. The final comparison must be done in order to identify the changes of fractional parameter with time. Regarding the theoretical part, one more paper has been published in August of this year, and the results have been presented in the XI All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics in Kazan. However, we are planning to publish our experimental results as separate papers in the future.

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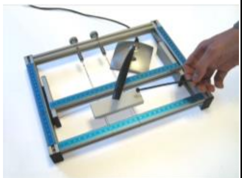
Table 1 Comparison of different kinds of equipments for the internal friction measurements

| Options | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Title | DTM-II-H Dynamic Elastic Modulus Damping Internal Friction Analyzer | Yong's Modulus and Damping Meter IE-RT | RFDA basic | RFDA professional |
| Manufacturer | Hunan Zhenhua analysis instrument co. ltd, China | Nippon Techno-Plus Co., Ltd, Japan | IMCE, Belgium | IMCE, Belgium |
| Photo |  |  |  |  |
| Measurements | Dynamic Elastic Modulus, Internal friction (10E-5 – 0.1), shear modulus and Poisson's ratio | Dynamic Elastic Modulus, Internal friction | Young's modulus, Shear-modulus and Poisson's ratio, Internal friction (10E-5 – 0.1) | Young's modulus, Shear-modulus and Poisson's ratio, Internal friction (10E-5 – 0.1), high temperature measurements, automatic excitation device |
| Method | Bending resonance method | Impact method | Impulse excitation method | Impulse excitation method |
| Sample types | 150×150×400 mm, rhomboid | Bar with uniform rectangular or circular cross section | Bars, discs; no any restrictions in terms of dimensions and cross-section | Bars, discs; no any restrictions in terms of dimensions and cross-section |

| Standards | ASTM C-215, ASTM C-666, GB/T13665-2007 | ISO12680 and ASTM-E1876 | ASTM C1259–ASTM E 1876 | ASTM C1259–ASTM E1876, ASTM C1259–ASTM E1876-01 |
|---|---|---|---|---|
| Documentation | No | Yes | Yes | Yes |
| Price | USD 12,000 | USD 30,000 | EUR 7,125 ~USD 7,550 | EUR 25,800 ~USD 27,300 |

Table 2 Concrete mix proportions for 1 cubic meter of fresh concrete

| Concrete | Water, kg | Cement, kg | Fine ag., kg | coarse ag., kg | SP, kg |
|---|---|---|---|---|---|
| $m^3$, kg | 213.85 | 484.75 | 796.38 | 881.46 | 2.200 |

Table 3 Specifications of rods

| Round bar | | | | |
|---|---|---|---|---|
| Number | diameter, mm | length, mm | mass, g | |
| 1 | 15.85 | 166.07 | 254.01 | |
| 2 | 15.85 | 326.16 | 498.88 | |
| Rectangular bar | | | | |
| Number | a, mm | b, mm | length, mm | mass, g |
| 3 | 19.68 | 19.41 | 91.61 | 262.61 |
| 4 | 19.7 | 19.42 | 181.34 | 519.7 |

Table 4 Compressive strength development

| Compressive Strength, MPa | | | | |
|---|---|---|---|---|
| Age, days | Sample 1 | Sample 2 | Sample 3 | Average |
| 3 | 36.281 | 36.283 | 36.280 | 36.281 |
| 7 | 38.481 | 39.376 | 40.271 | 39.376 |
| 14 | 43.133 | 43.082 | 43.107 | 43.107 |
| 28 | 48.804 | 49.224 | 49.644 | 49.224 |

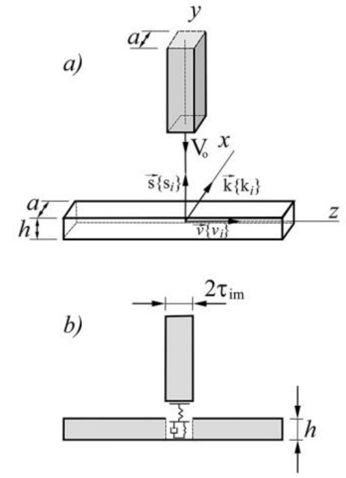



Fig.1 Problem formulation [3]

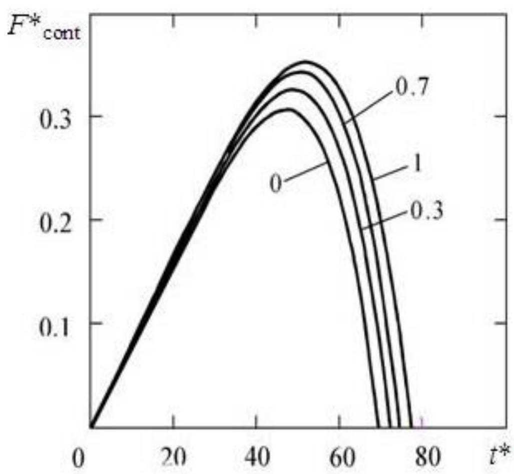



Fig. 2 Dimensionless contact force vs. dimensionless time [3].

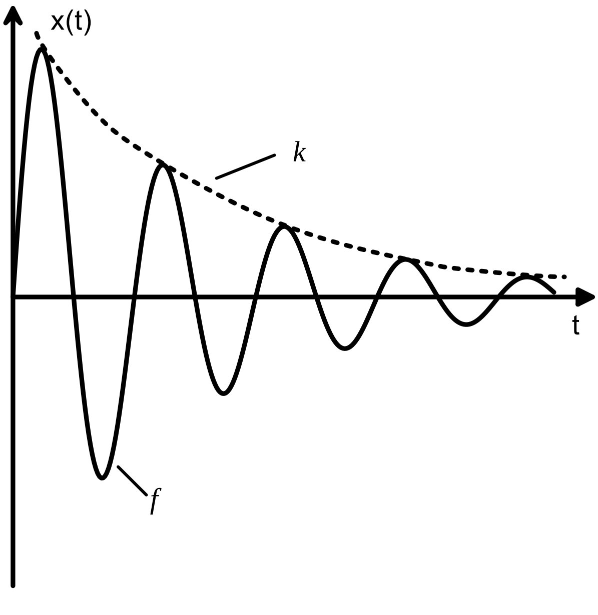



Fig. 3 Sinusoidal damped vibrations

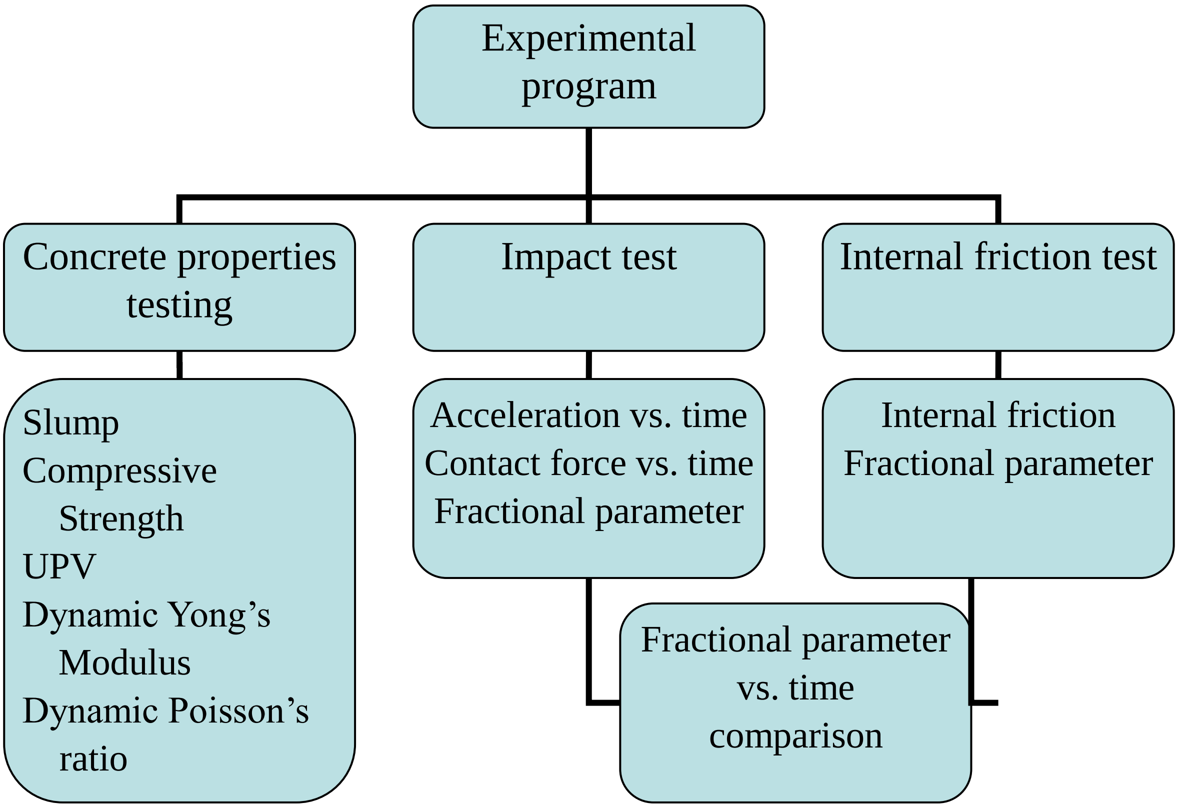



Fig. 4 Experimental program diagram

Fig. 5 Slump test of fresh concrete

Fig. 6 Concrete cylinders

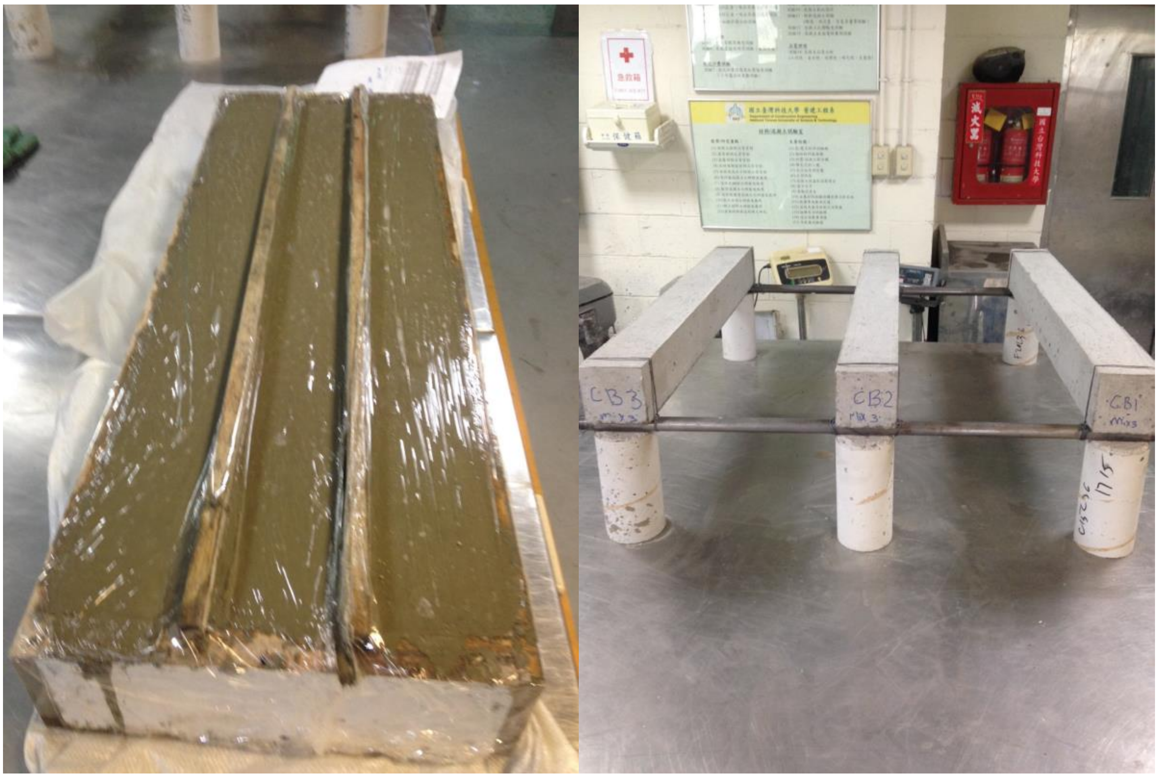



Fig. 7 Timoshenko type concrete beams (100×100×1000 mm)

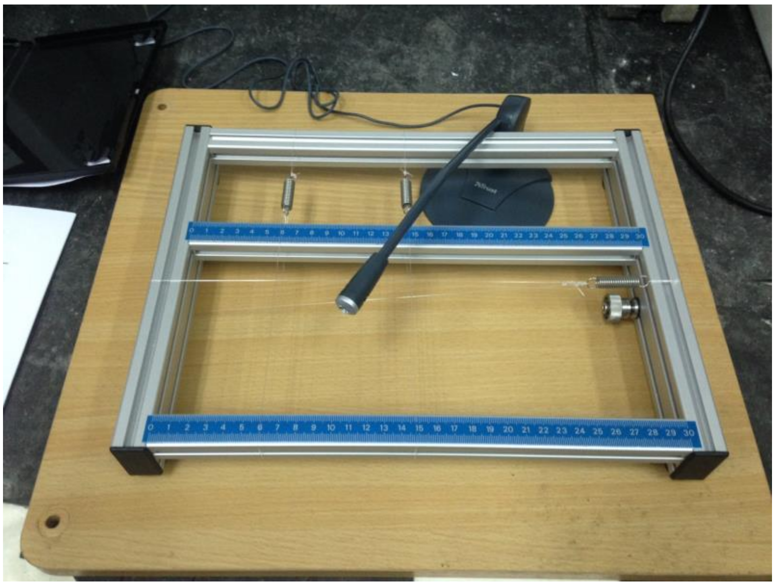


Fig. 8 Original supporting device of RFDA basic

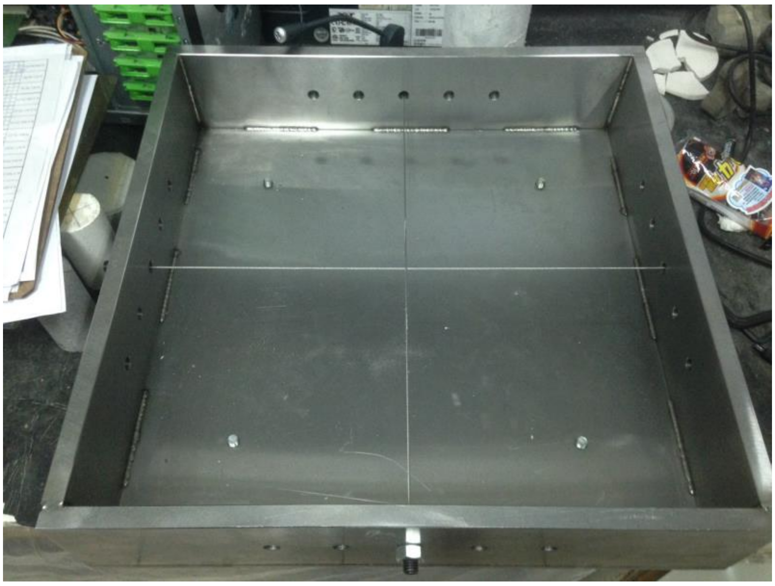


Fig. 9 Supporting device designed by TW team

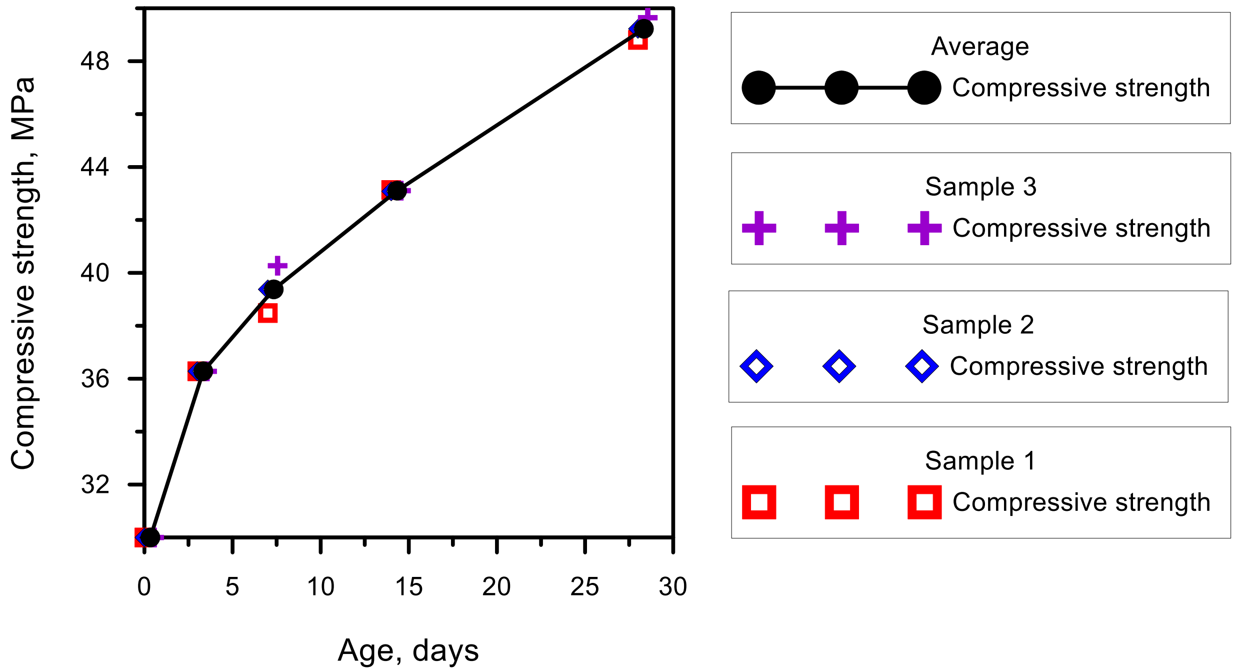



Fig. 10 Compressive strength development

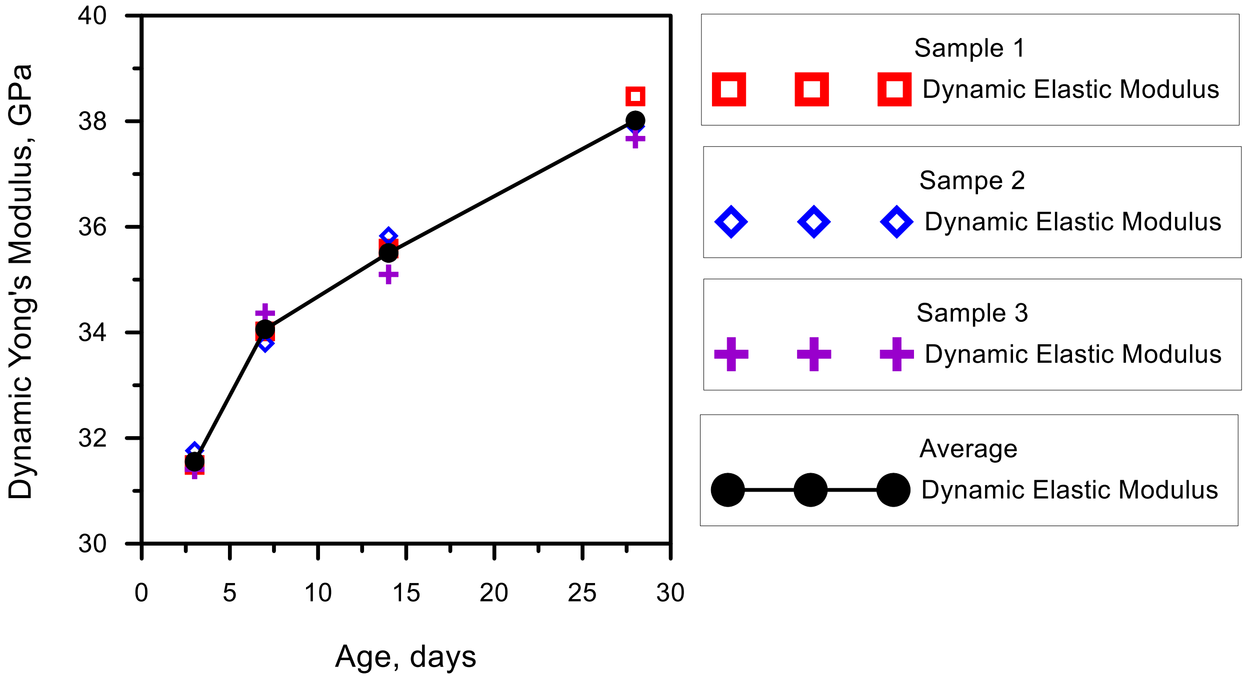



Fig. 11 Dynamic Yong's Modulus vs. time

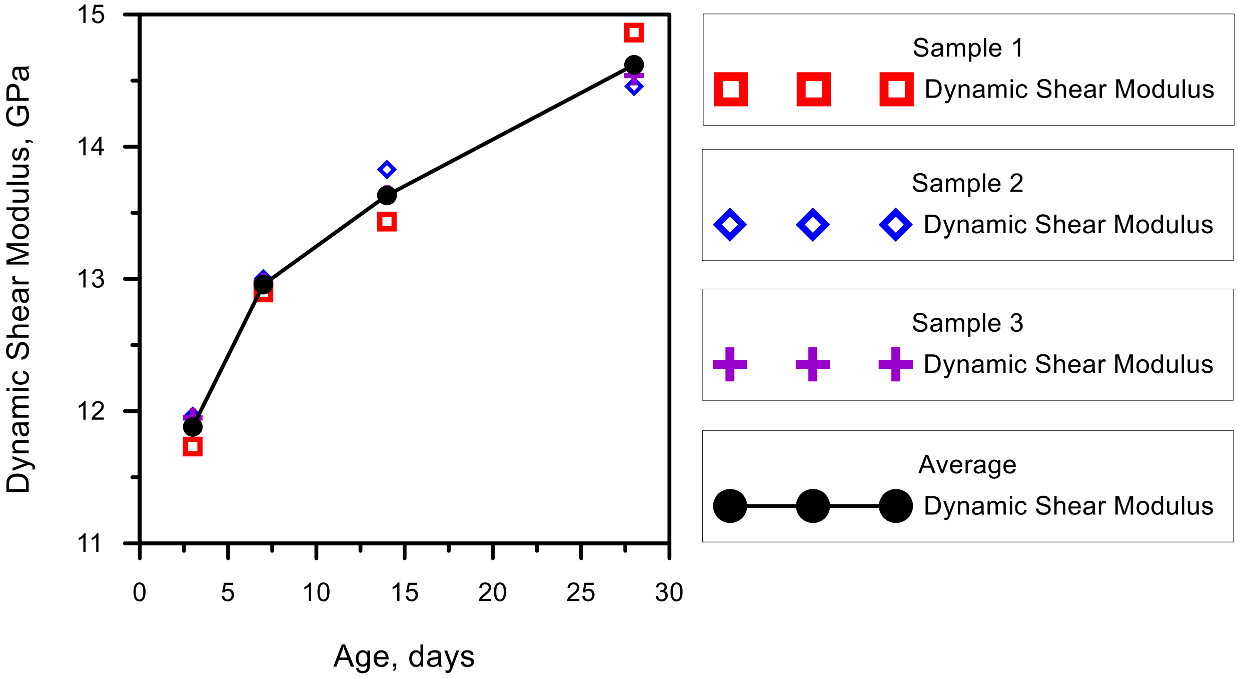



Fig. 12 Dynamic Shear Modulus vs. time

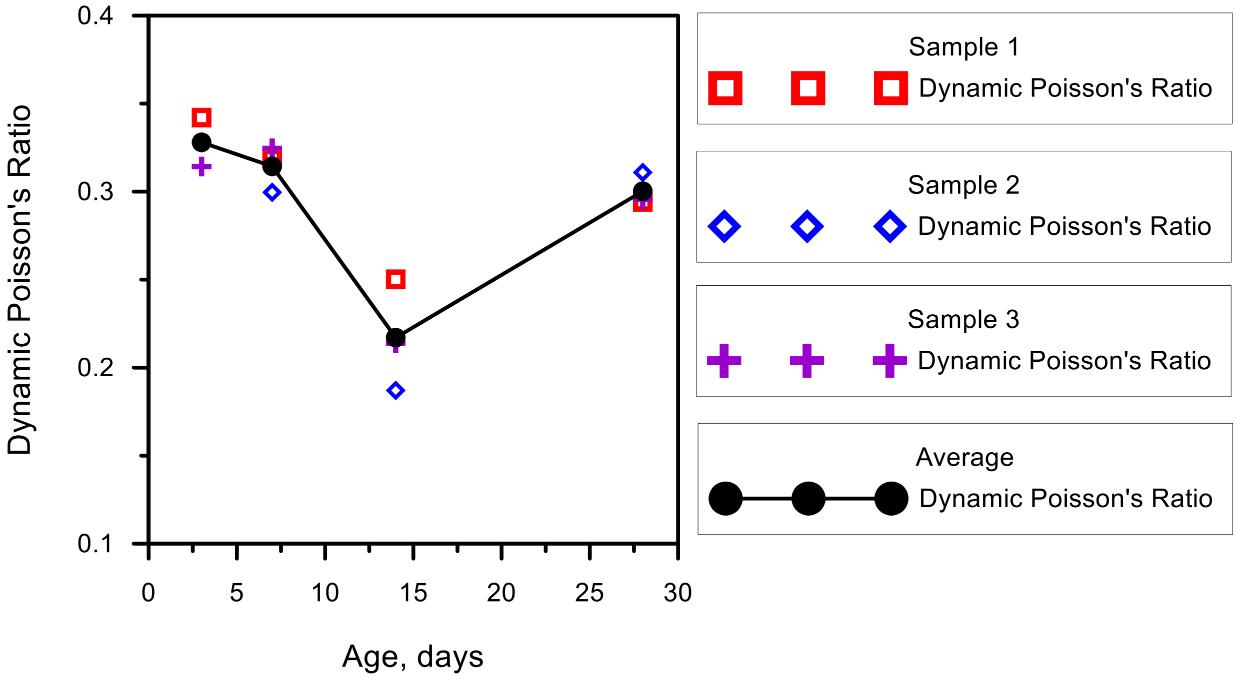



Fig. 13 Dynamic Poisson’s ratio vs. time

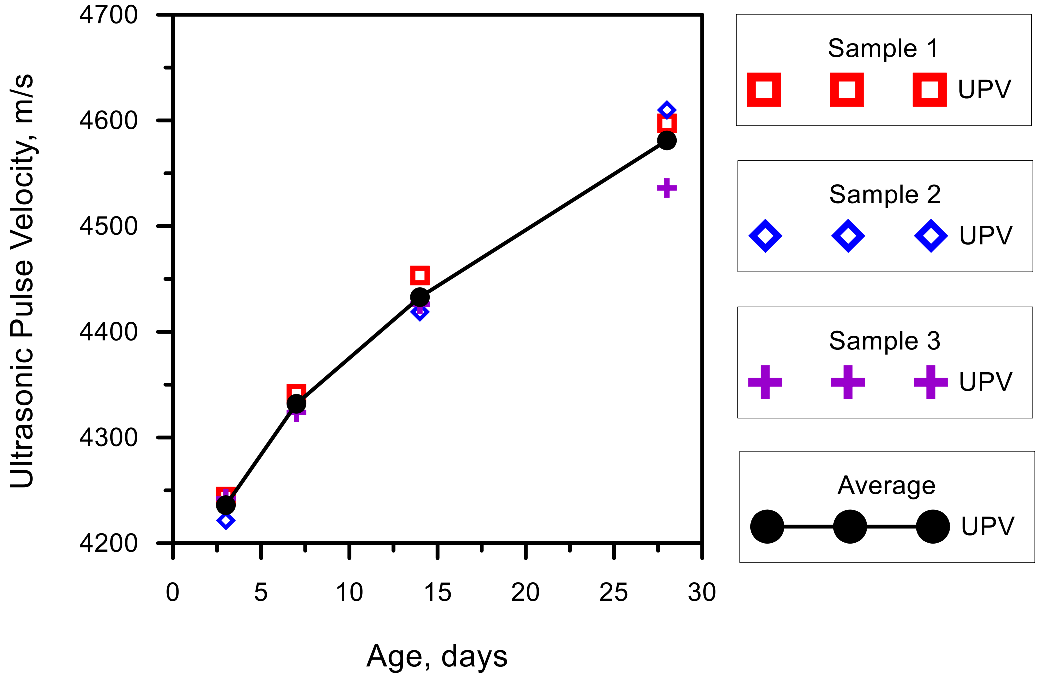



Fig. 14 Ultrasonic Pulse Velocity vs. time

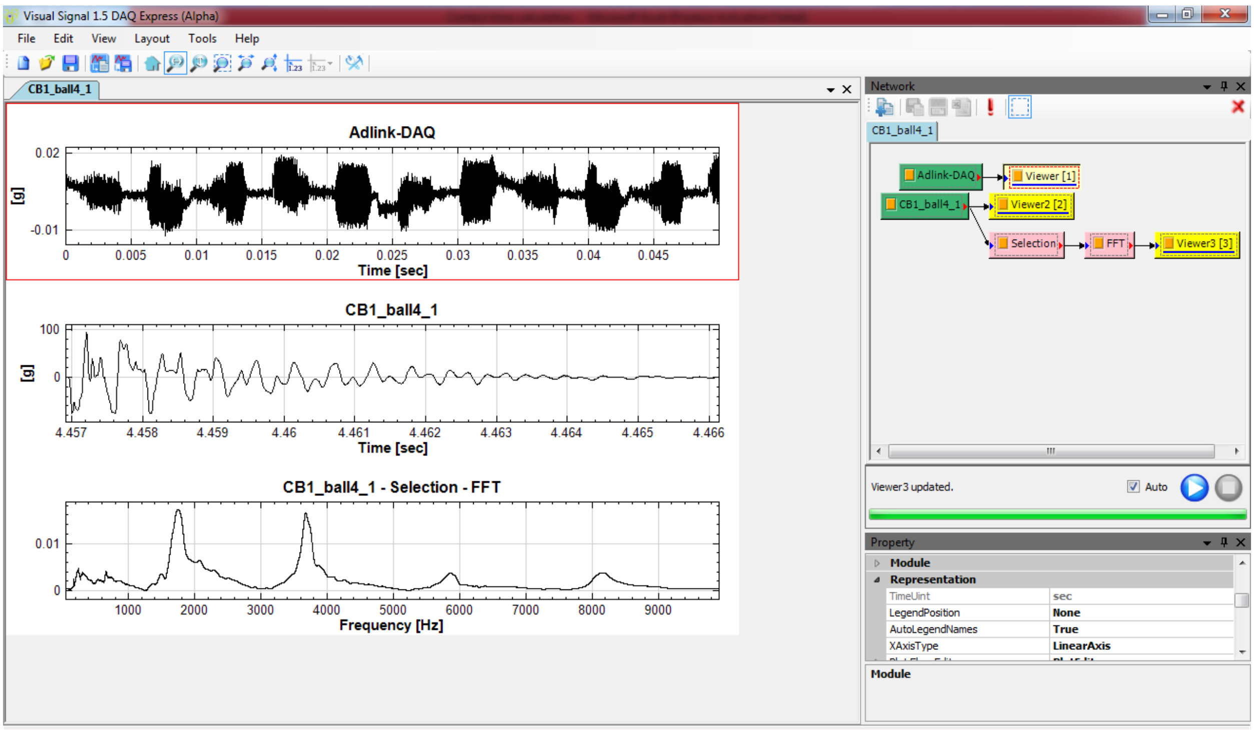



Fig. 15 Beam test results, Beam 1, age 7 days, ball#4, impact 1

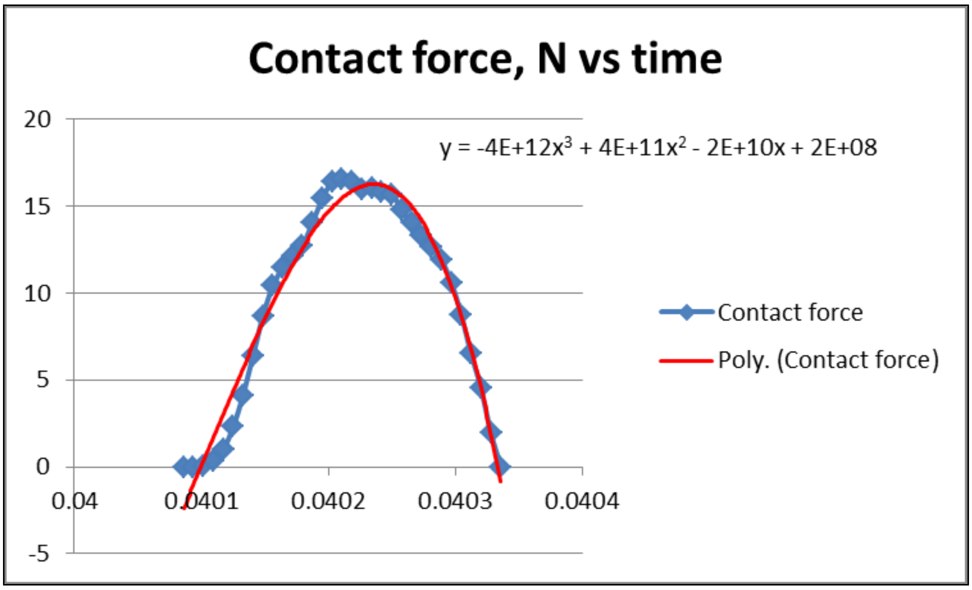



Fig. 16 Experimental contact force and its analytical approximation

Fig. 17 Experimental setup for the internal friction test

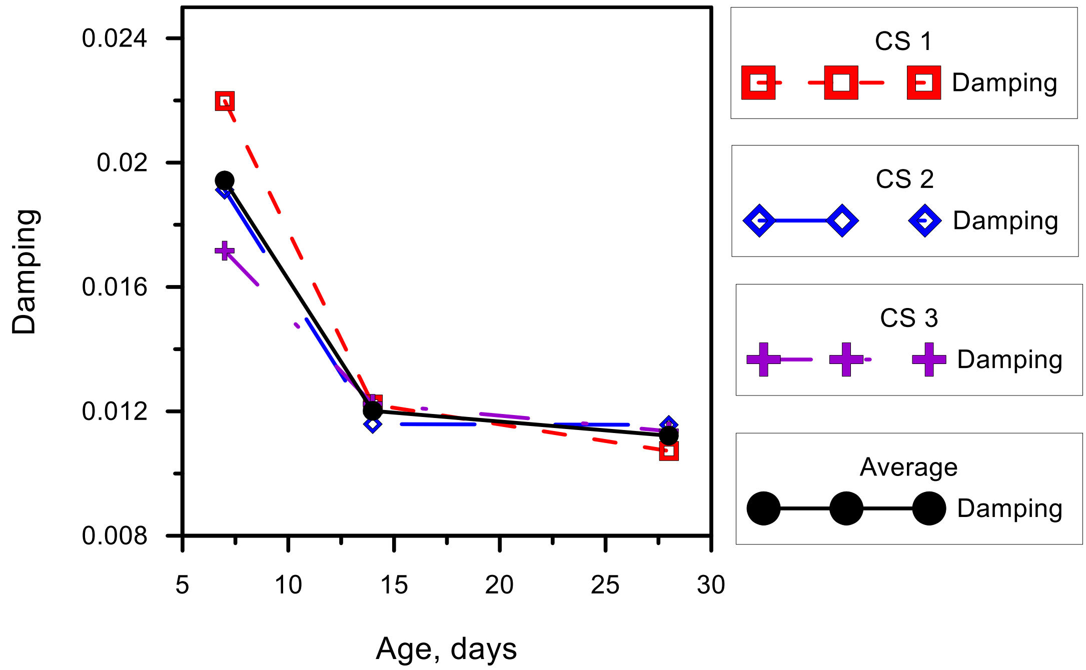



Fig. 18 Damping vs. time

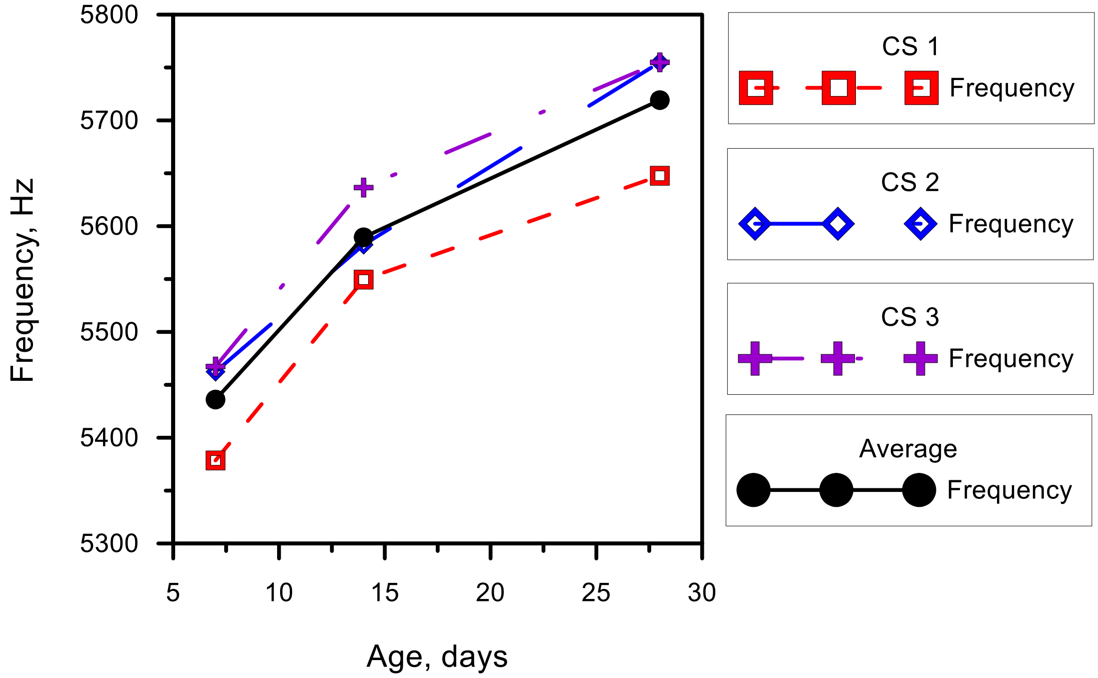



Fig. 19 Frequency vs. time

Statistic Data of the Join Research Cooperation

**I. Number of Staff working in the joint project** – the "staff type" including: principal investigator (PI), collaborating principal investigator (co-PI), assistant investigator, and postdoctoral research fellow.

| Staff Type | Taiwan Side | Russia Side |
|---|---|---|
| PI and Co-PI | Distinguished Prof. Chang Ta-Peng | Full Prof. Shitikova Marina V., Distinguished Prof. Rossikhin Yurii A. |
| Full-time research assistant | Ph.D. candidate Popov Ivan | |
| Part-time research assistant | PH.D. student Hoang Anh Nguyen | Assistant prof. Nataliya A. Nekrasova, Ph.D. student Maria Estrada Mendos |
| Postdoctoral Research Fellow | Assistant Prof. Chen Chun-Tao | |

## II. Joint publication(s) (by the date of this report submitted)

1. Scientific Journal Information for Papers Being Published or Accepted

| Title of Paper | Name of Journal | SCI/EI /SSCI | Impact Factor | Volume No. | Date |
|---|---|---|---|---|---|
| Impact response of a viscoelastic beam considering the changes of its microstructure in the contact domain | Mechanics of Time-Dependent Materials | SCI | 1.587 | Online | 2015.08.04 |
| | | | | | |

2. Monographs and Articles in Books Being Published or Accepted

| Title of Article, Monograph | Name of Book, Publishing House | SCI/EI/SSCI | Impact Factor |
|---|---|---|---|
| | | | |
| | | | |

3. International or Domestic Conferences and Symposiums

| Title of Paper | Name of Event | Organizer of the Event | Date |
|---|---|---|---|
| Impact response of a viscoelastic beam considering the changes of its microstructure in the contact domain | The XI$^{th}$ All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics | The Russian National Committee on Theoretical and Applied Mechanics jointly with the Kazan Federal University and the Institute of Mechanics and Mechanical Engineering of the RAS Kazan Scientific Center | 20.08.2015 – 24.08.2015 |
| | | | |
| | | | |

4. Other Publishing Plan of Papers, Articles or Monographs [Submitting or Under-reviewing】

| Title of Paper, Article or Monograph | Name of Journal, Publishing House | SCI/EI/SSCI | Impact Factor |
|---|---|---|---|
| | | | |
| | | | |

## III. Joint application for Patent rights or Technology transfer (if applicable)

☐ **Patent** ☐ **Technology transfer**

| | |
|---|---|
| Name of Invention or Technology | |
| Technology Description (max. 200 words) | |
| Technique Features | |
| Applicable Industry or Potential Product for Commercialization | |
| Patent Issued Country | |
| Patent Period | |

Note: please don't describe the major content if you haven't got the patent issued

## IV. Data of Personnel Exchange

### 1. Visiting Russia from Research Teams working in Taiwan

| Date of Visiting | Main Task and Result | Total member of visiting team/country |
|---|---|---|
| 2015/08/06 – 2015/08/26 | Theoretical studies, preparation and attendance of The XI$^{th}$ All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics | Ivan Popov |
| 2015/08/19 – 2015/08/26 | Attendance of The XI$^{th}$ All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics, Visit Voronezh State University of Architecture and Civil Engineering | Prof. Chang, Ta-Peng |

### 2. Visiting Taiwan from Research Teams working in Russia

| Date of Visiting | Main Task and Result | Total member of visiting team/country |
|---|---|---|
| | | |

## V. Pattern of Cooperative Research

- ☐ Data collection sharing

- ☐ Research information exchange

- ☐ Model of theory establishment and inspection
- ☐ Data induction or deduction
- ☐ Device or product design
- ☐ Others (please specify) ________

# 科技部補助專題研究計畫出席國際學術會議心得報告

2015 年 09 月 04 日

| | | | |
|---|---|---|---|
| 計畫編號 | NSC 103-2923-E-011 -002 -MY3 | | |
| 計畫名稱 | 以羅伯諾夫分數階運算元(Rabotnov's fractional operators)探討混凝土結構物承受撞擊時之動態行為 | | |
| 出國人員姓名 | 張大鵬 | 服務機構及職稱 | 國立臺灣科技大學 營建系 教授 |
| 會議時間 | 2015 年 8 月 20-24 日 | 會議地點 | 喀山，俄羅斯(Kazan, Russian Federation) |
| 會議名稱 | (中文) 第 11 屆理論與應用力學基礎問題全俄研討會<br>(英文) The XIth All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics | | |
| 發表論文題目 | (中文) 考量接觸區微觀結構變化之彈性桿與黏彈性樑衝擊交互作用分析<br>(英文) Analysis of Impact Interaction of Elastic Rod and Viscoelastic Beam, Taking into Account Its Microstructure Change in the Contact Zones | | |

報告內容應包括下列各項：

一、參加會議經過

二、與會心得

三、發表論文全文或摘要

四、建議

五、攜回資料名稱及內容

六、其他

一. 參加會議經過

「第 11 屆理論與應用力學基礎問題全俄研討會會」於 2015 年 8 月 20-24 日在俄羅斯喀山市(Kazan, Russian Federation))舉行，國人到俄羅斯須辦簽證，報告人到台北市信義路 5 段 2 號 9 樓，「莫斯科台北經濟文化協調委員會駐台北代表處」委託「雙都經貿顧問有限公司」代理收送辦理，如申請資料完整無誤，當天即可取得蓋在護照上之簽證。

喀山(Kazan)為俄羅斯韃靼斯坦共和國(Tatarstan Republic)首都及最大城市，根據俄羅斯 2010 年人口調查，居民為 1,143,600 人，為俄國第八大城市，位於莫斯科東邊約 720 里，屬於俄羅斯歐洲部分，與莫斯科、聖彼得堡同為俄羅斯之三座 A 級歷史文化城市，喀山市市中心目前只有一條長約 10 公里共 7 個站之地鐵，於 2005 年 8 月 27 日開始啟用；報告人須先搭飛機抵達莫斯科後再轉機到喀山，但出發、到達或與轉機之飛機航班安排不很理想，所以報告人選擇 8 月 19 日(週三)早上搭 07:25 中華航空班機，09:15 到香港國際機場，再轉搭俄羅斯航空公司(Aeroflot Russia Air)11:10 班機，16:10 抵達莫斯科雪瑞米耶佛國際機場(SVO)，當

晚住宿在機場附近之 Skypoint Hotel，隔天(8 月 20 日)早上搭 09:10 俄羅斯航空公司國內班機，10:40 抵達喀山國內機場，與報告人博士班學生 Mr. Ivan Popov 會合後，搭計程車住在喀山市中心，任在旅館 Grand Hotel Kazan，安頓妥當後，隨即步行到會議地點喀山國立大學(Kazan State University)完成註冊報到，報告人論文於莫斯科時間 8 月 21 日(五)下午 5:00 之小型研討會會場完成報告。

隨後報告人於 8 月 23 日於喀山機場，搭 21:15 俄羅斯航空公司班機，22:45 到莫斯科，再轉 23:50 班機，8 月 24 日凌晨 0055 到佛羅尼斯(Voronezh, Russia)國內機場，搭車前往市中心，在旅館 Holiday Inn Express 住宿 3 天，出席三年期國科會臺俄(RU)雙邊協議專案型國際合作研究計畫(核准計畫編號：NSC 103-2923-E-011 -002 -MY3)第二年雙邊科技交流，與此雙邊協議專案型國際合作研究計畫俄方研究團隊：俄羅斯國立佛羅尼斯建築與土木工程大學(Voronezh State University of Architecture and Civil Engineering, Voronezh, Russia)希提可娃教授(Prof. Marina V. Shitikova)，同討論此項三年期國際合作計畫研究案第二年相關試驗與數值分析研究方法及其它研究相關議題，完成後，於 8 月 26 日早上在佛羅尼斯(Voronezh, Russia)國內機場搭 11:20 班機，12:25 抵達抵達莫斯科雪瑞米耶佛國際機場(SVO)，再轉 19:15 俄羅斯航空公司，8 月 27 日早上 09:35 抵達香港國際機場，再轉搭中華航空 11:05，12:45 抵達國內桃園國際機場，再回到台北，完成此次研討會及台俄雙邊科技交流全部行程。

二**.** 與會心得

「第 11 屆理論與應用力學基礎問題全俄研討會」(The XIth All-Russian Congress on Basic Problems of Theoretical and Applied Mechanics)由 Russian National Committee on Theoretical and

Applied Mechanics 結合 Kazan (Volga region) Federal University 及 Institute of Mechanics and Mechanical Engineering of the RAS Kazan Scientific Center 共同主辦，協辦單位包括 Russian Academy of Sciences、Ministry of Education and Science of the Russian Federation、Federal Agency for Scientific Organizations、Government of the Republic of Tatarstan 及 Russian Foundation for Basic Research，規模很龐大，在喀山國立大學 (Kazan State University)校園內舉行，喀山國立大學成立於 1804 年 11 月 5 日，由當時沙皇亞歷山大一世(Russia Emperor Alexander the First)簽署成立，位於韃靼斯坦共和國首府喀山市市中心，是俄羅斯繼莫斯科大學和聖彼得堡大學之後成立之第三所古老大學，共有 15 學院，15000 個大學部學生及 615 位研究生，有 1137 教師(含 208 教授)，在俄羅斯之學術地位很高，是俄羅斯東部地區最高等學府，也是最有影響力之文教科研中心，蘇聯時期有名人物如列寧、托爾斯泰等名人，在青年時代都曾在喀山大學就讀，先後有 50 多名教師被選為俄羅斯（蘇聯）科學院院士，進出校區各大樓均有警衛守護，須有學生證/教職員工證，方可進出。

本次研討會共有 Oral 及 Poster 論文 1518 篇，其中 Oral 論文共 736 篇，議程共分為四個主題，如下所示：

**Section I. General and Applied Mechanics**
I – 1. Analytical Mechanics and Stability of Motion
I – 2. Control and Optimization of Mechanical Systems
I – 3. Vibrations of Mechanical Systems
I – 4. Mechanics of Systems of Rigid and Deformable Bodies
I – 5. Mechanics of Machines and Robots
I – 6. Symposium: Mechanics of Space Flight

**Section II. Fluid Mechanics**
II – 1. Hydrodynamics
II – 2. Aerodynamics and Gas Dynamics
II – 3. Flow Stability and Turbulence
II – 4. Physico-Chemical Mechanics of Continua
II – 5. Mechanics of Multiphase Media

**Section III. Mechanics of Deformable Solids**

III – 1. Theory of Elasticity and Viscoelasticity
III – 2. Theory of Plasticity and Creep
III – 3. Dynamic Processes in Deformable Media
III – 4. Fracture and Damage Mechanics
III – 5. Mechanics of Contact Interaction
III – 6. Symposium: Structural and Mechanical Properties of Materials
III – 7. Symposium "Problems of Optimization, Identification and Reliability"

**Section IV. Multidisciplinary Problems in Mechanics**
IV – 1. Problems of Mesomechanics and Nanomechanics
IV – 2. Biomechanics
IV – 3. Mechanics of Natural Processes
IV – 4. History of Mechanics and Problems of Teaching of Mechanics in Higher Education

研討會全部會議時間總共有 5 天，每天均有安排議程，詳細議程如下：

**August 20, 2015**
09:30 – 13:00. Opening ceremony, greetings. First plenary meeting
13:00 – 14:00 Lunch break
14:00 – 16:00 Second plenary meeting
16:00 – 16:30 Coffee break
16:30 – 18:30 Third plenary meeting

**August 21, 2015**
09:30 – 11:00 First listening of sections I,II,III
11:30 – 12:30 Second listening of sections I,II,III
12:30 – 14:00 Lunch break
14:00 – 15:45 First listening for all subsections
15:45 – 17:30 Poster of all the subsections of Section II and subsections 4-3
16:30 – 17:00 Coffee break
17:30 – 19:00 Second listening of all subsections

**August 22, 2015**
09:30 – 11:00 Third listening of sections I,II,III
11:30 – 12:30 Forth listening of sections I,II,III
12:30 – 14:00 Lunch break
14:00 – 15:45 Third listening for all subsections
15:45 – 17:30 Poster of Section I and symposium 3-7, subsections of Section III, subsections 4-1, 4-2, 4-4
16:30 – 17:00 Coffee break
17:30 – 19:00 Forth listening of all subsections

**August 23, 2015**
09:30 – 11:00 Fifth listening of sections I,II,III
11:30 – 12:30 Sixth listening of sections I,II,III
12:30 – 14:00 Lunch break
14:00 – 19:00 Free time, cultural program
19:00 – 22:00 Gathering dinner

**August 24, 2015**
09:30 – 12:30 Fifth listening of sections I,II,III
12:30 – 14:00 Lunch break

14:00 – 15:00 Ending ceremony
15:30 – 17:00 Meeting of Russian National Committee on Theoretical and Applied Mechanics

在由此次參與研討會中，可瞭解俄羅斯對於此研討會主題「理論與應用力學基礎問題」研究方向及最新發展，除在學術上的收獲外，對於當地的交通建設及豐碩人文藝術的親身體驗，也開拓更廣闊之視野。

三. 考察參觀活動**(**無是項活動者省略**)(**略**)**

四. 建議

理論與應用力學基礎問題科技領域近年來的學術發展與研究日新月異，國內學者可多參加國際研討會，雖會多花費一些時間準備各項出國資料、手續及研討會論文，但可增加與國際各國學者之交流機會，增進見聞，增厚我國日後在世界理論與應用力學基礎問題科技舞台之競爭力與研發層次。

五. 攜回資料名稱及內容：研討會會議之論文集。

六. 其他 (無)