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A REVIEW ON EXISTING QUALITY OF BRIDGES USING REBOUND HAMMER AND RESISTIVITY TEST

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ABSTRACT: The aim of this study was to find out the quality of bridges using non-destructive tests. The study was conducted during the period from December 2017 to February 2018. Intensive literature survey was the technique of this study. There are several techniques to monitor the structure of bridges like condition assessment through visual inspection along with non-destructive test (NDT). This paper focuses on condition assessment along with standard testing procedure of NDT. It also describes the sequence of operation for obtaining accuracy as well as the problem associated during the test. The study found that the bridges are not so safe due to various problems such as presence of black cotton soil, scouring of the sand in the bridge pier, problem in expansion joints like wear and tear, in bearing like rusting, in Parapet wall like hitting by vehicles, minor and moderate cracks due to degrade in quality of concrete, and default designs.

KEYWORDS: Non-destructive test; Conditional assessment; Resistivity test; Rebound hammer test.

1 INTRODUCTION

During 18th century, there were many invention in the design of timber bridges by Hans Ulrich Grubenmann, Johannes Grubenmann, and others [1]. The first bridges made by humans were probably spans of cut wooden logs or planks and eventually stones, using a simple support and crossbeam arrangement. A common form of heavy sticks, logs, and branches together involved in the use of long stems or other harvested fibers woven together to form a huge rope capable of binding and holding together the materials used in early bridges[1].

A major breakthrough in bridge technology came with the erection of the Iron Bridge in Shropshire, England [2]. It used cast iron for the first time as arches to cross the river Severn. With the Industrial Revolution in the 19th century, truss systems of wrought iron were developed for larger bridges, but iron does not have the tensile strength to support large loads [2]. With the advent of steel, which has a high tensile strength, much larger bridges were built, using the ideas of Gustave Eiffel. In 1927 welding pioneer Stefan Bryła designed the first welded road bridge in the world, the Maurzyce Bridge which was later built across the river Słudwia at Maurzyce near Łowicz, Poland [3]. In 1995, the American Welding Society presented the historic welded structure award for the bridge to Poland. The tenets (system or code) of Vitruvius identified provides a simple and valid basis for judging the quality of bridge and building structure today. According to the mentioned code 'Firmness' is the most basic quality and a bridge must possess and relate to the structural integrity of the design, the choice of material used which comes under the quality of the material used and the durability of the construction. 'Commodity' refers to the function of the bridge, and how it serves the purpose for which it was designed. This quality is lacking in any bridge design, whether it is ugly to look or good to look at. Therefore, quality control in bridge is very important [1].

Quality control of RCC bridges is the basic term for application during construction at site [4]. It may be defined as a system that is used to maintain a desired level of quality in a product or service. It may be achieved through different measures such as planning, design, use of proper equipment, procedure or methodology and inspection [1]. If any changes is observed then correction should be done between the product, service or process output with a specified standard [5].

In Nepal, there are over 1200 bridges constructed by Department of Roads (DOR). Out of over 1200 DOR built bridges 1056 of them lie in the Strategic Road Network (SRN) and design of bridges are done through Bridge Unit of DOR [6]. Construction of Bridges is done by the road division offices or the relevant project offices of the DOR. Bridge Branch Unit (BBU) is responsible for planning, design drafting policy and standards for inspection and maintenance of the bridges in Nepal [6].

Concrete is widely used for the construction of infrastructures such as bridges, power stations, dams, etc. Presence of voids particularly in the cover zone of reinforced concrete structure leads to early corrosion of the reinforcement [7]. Deterioration rate of the structures depends upon the exposure conditions and extent of maintenance. Usually, there are two major factors which causes corrosion of rebars in concrete structure, carbonation and ingress of chloride ions. When carbonation depth exceeds concrete cover then it start corrosion in reinforced concrete structures. When corrosion start in concrete structures, it progresses and reduces life of the structure. Corrosion of steel bars is major causes of failure of concrete structure. So, corrosion can be prevented using low permeable concrete [8]. To detect the corrosion NDT along with resistivity test gives idea about the corrosion in reinforced concrete structures [8]. Non-destructive test in reinforced concrete structure plays a very important role for the condition assessment which includes identification of defects such as honeycombs, voids, cracks, etc. [7].

In recent years, innovative NDT methods are used for the assessment of existing structure which has been available for concrete structures but is not still established for regular inspection. Therefore, the objective of this study is to investigate the applicability, performance, availability, complexity and restriction of the NDT [9]. For assessment of existing quality condition of bridge concrete structures, condition assessment is done by visual inspection with the help of the format which includes various components of bridge structures and rate them according to the existing structural condition. With the help of photographs the structural damage may be identified for the condition rating of the bridge. Structural monitoring means the process of detecting damages. Assessment can be useful for recognition of potential damage to structure and to identify the probability of damage [10]. Damage assessment is carried out through non-destructive evaluation (NDE) techniques like rebound hammer and combined method in the structure [11]. Non-destructive techniques can be used effectively to investigate and evaluate the actual condition of the structures. These techniques are relatively cheap, quick and easy to use and also give a general ideas of the required property of the concrete [10]. Non-destructive test is defined as a method used to investigate the integrity of an object, material or system without impairing its future usefulness or the use of noninvasive techniques to determine the integrity of a material, component or structure [12]. The materials and the structures need to be assessed for their conditions. Damage is localized by non-destructive methods without inflecting new damage on the examined by the test method themselves. The technological advances in this field and the knowledge thereof help avoid additional expenditure.

Non-destructive test methods are applied to bridge concrete structure for four primary reasons. These are: quality control of new construction, troubleshooting of problems with new construction, condition evaluation of older concrete for rehabilitation purposes and quality assurance of concrete repairs [12].

Non-destructive test methods are increasingly applied for the investigation of concrete structures. The increase in the application of NDT methods is due to a number of factors such as technological improvements in hardware and software for data collection and analysis, the economic advantages in assessing large volumes of concrete compared with coring, ability to perform rapid, comprehensive assessments of existing construction; and specification of NDT methods for quality assurance of deep foundations and concrete repairs [13].

Traditionally, quality assurance of concrete construction has been performed largely by visual inspection of the construction process and by sampling the concrete for performing standard tests on fresh and hardened specimens. This approach does not provide data on the in-place properties of concrete. NDT methods offer the advantage of providing information on the in-place properties of hardened concrete such as the elastic constants, density, resistivity, moisture content and penetrability characteristics [12].

The necessity of conducting NDT for RCC bridge structures has risen considerably in recent times, due to increment in number of bridge structures showing the sign of stress. As reported the standard life of RCC frame structure is 60 to 80 years, many of the building structures completing 20 to 25 years of life is likely to expose to chemical attack, honeycomb, etc. The RCC structures are found to be in distressed condition in 7-10 years after the completion of structures [14]. The main reason for this deterioration is the severe exposure condition. So, NDT is necessary for structural monitoring of buildings, bridges, dam and other structures. The main objectives of the assessment is to ensure that structure & its different parts do not fail under its loading condition. Assessment is carried out so that its maximum resistance capacity can be observed. NDT can be used to detect cracks, voids, fractures, honeycombs & weak locations, damaged assessment due to fire, chemical attack, impact, age, etc, assessing the actual conditions of superstructure & sub-structure of bridge, monitor progressive changes in properties, assess overall stability of the structure, test any number of points and any locations [14].

NDT equipment like Schmidt rebound hammer and resistivity test is carried out to find the existing quality condition of bridges. This equipment is discussed below:

Schmidt hammer or rebound hammer

This particular device is used to measure the surface hardness of concrete. Corrections will be made in accordance with IS 13311 (Part 2): 1992, [15].This test is generally conducted on the accessible regions of RC structure to access the strength of concrete [16].

Resipod

This particular device is used to measure the quality of the cover concrete & also the probability/ chances of corrosion of reinforcement bars & also the idea of durability of concrete[15].This test is generally conducted on the accessible regions of RC structure to access the probability/ chances of corrosion of reinforcement bars and durability of concrete.

1.1 Concept and definition of bridge

Bridge is a structure having a total length of above 6 meters between the inner faces of the dirt walls for carrying traffic or other moving loads over a depression or obstruction such as channel, road or railway [16]. Victor defined the bridge as a structure providing passage over an obstacle without closing the way beneath [17, 18]. The required passage may be for a road, a railway, pedestrians, a canal or a pipeline. The obstacle to be crossed may be a river, a road, railway or a valley [19]. A bridge is defined by the Nepal Road Standards (2027) as a structure more than 6 meters in length. Less than 6m in length, structures are classified as culverts and are not included in the bridge inventory [20].

1.2 Review of basic theories, model and techniques

In the construction of bridges there is the problem arises due to narrow space, similarly there is a problem of soil i.e. weak soil. While designing the structure for the bridge we need to design bridge considering the seismic effect of the earthquake, maximum discharge of the flood effect, clear visibility of the road from the bridge, effect of the bridge for the community, environmental and social issues arises from the bridges and so on.

There are other problem like presence of black cotton soil due to which extra seismic appropriate design like base isolation need to be carried out which can be costlier for the construction of new bridges. There is the problem of scouring of the sand in the bridge pier seen in river due to the sand taken from the river bed for the construction by the contractor.

While talking about quality of existing bridges in bridges there are problem seen in expansion joints like wear and tear, in bearing like rusting, in parapet wall like hitting by vehicles, in pier, back wall, stopper, body cap like minor and moderate crack due to degrade in quality of concrete which is due to low bidding by the contractor, default design, contractor unaware of the contract documents and specification, etc.

2 PRINCIPLE AND METHODOLOGY

2.1 Bridge inspection on existing quality condition of bridges

Bridge inspection is an essential element of any bridge management system particularly for aged and deteriorated bridges and a path way to condition rating for the existing quality of bridges [5]. The accuracy of condition assessment is relied heavily on the quality of the inspection. To reduce fixed costs and to enhance efficiency, an inspection system must be planned at the bridge network level and not at the single bridge level [21].

The model and techniques for existing quality condition of bridge can be summarized according to the Bridge Inspection Manual published by DOR. These are as follows:

- Routine Inspection (RI)
- Superficial Inspection (SI)
- Principal Inspection (PI)

- Special Inspection

Routine Inspection (RI)

It is essentially a visual inspection, possibly supplemented by a few simple measurements. It should generally be undertaken at a time of low water so that substructures, the river bed and any bed protection can be inspected. The routine inspection is very important because the results of this inspection enable the divisions to plan the annual bridge maintenance work. Simple access equipment, such as a ladder, is used from time to time to reach less accessible parts. Binoculars are used to inspect areas beyond the reach of a ladder. Timely inspection and preventative maintenance protect the National assets [18]. RI include adjacent earthworks or waterways, damage or other changes which can affect the stability of the structure. River banks in the vicinity are examined for evidence of scour or for other conditions such as deposition of debris, which could cause problems [20]. RI form include: bridge inspection report form and bridge identification and bridge inspection summary. The DOR standard rating system for bridges is used for RI [20].

Superficial Inspection (SI)

It is a quick check to find the damage or faults which might lead to the accidents or it may lead to high maintenance costs. Some examples are impact damage from vehicles, flood damage or insecure expansion joint plates. Such action can prevent the development of serious problems between routine inspections. Inspections are made from ground and deck level without the provision of access equipment. Any SI reveals a possible defect or hazard to the road user and division shall take such action as is required to safeguard the public [20].

Principal Inspection (PI)

Principal inspection is planned periodically. It consist of a more detailed inspection of the structure generally from within touching distance and often involving a certain amount of non-destructive testing. It will normally be undertaken by qualified bridge engineers, either from local consultants or from the DOR, bridge branch. The frequency of these inspections will probably be between five and eight years. New bridges however should have a PI as soon as practicable after completion and again four or five years later [20]. The PI is enhanced by a comprehensive report which will include site sketches, description of structure and inspection, maintenance history, photographs, notes, test results and interpretations of the results and other data. Other more specialized equipment such as paint thickness gauge, a depth of cover meter for reinforcement and tales may be needed on occasions [20].

Special Inspection

Special inspections required if the structure is at high risk or there may problem for further investigation. The frequency for special inspection may vary. Special inspection is done to address the special problem in the bridge which is found during the inspection or it has already occurred. Special inspection may be required after heavy abnormal load, earthquake, fire accidents, fuel spillage etc. Special inspection shall be carried out are when further detailed examination is needed to investigate a special problem, either found during inspection or already discovered on other similar structures. When a structure has to carry an abnormal heavy load, the inspection takes place before during and after the passage of the load if either an assessment has indicated that the margin of safety is below the current design standard or similar loads are not known to have been carried by the bridge. Special inspection is also carried out after a major accident, chemical or fuel spillage or fire adjacent to a structure to investigate possible damage to the structure [20].

2.2 Principles of rebound hammer test

Surface hardness tests are of indentation type and include impact hammers like rebound hammers. These are used only for estimation of concrete strength. It is also known as impact hammer test (IHT) or accelerometer test (AT) and is based on the principle that rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. It measures the elastic rebound of concrete and is primarily used for the estimation of concrete strength and for comparative investigations. The main objective of surface hardness test are as follows [15]:

- Assessing the likely compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength.
- Assessing the uniformity of concrete
- Assessing the quality of the concrete in relation to standard requirements and
- Assessing the quality of one element of concrete in relation to another.

This method is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which mass strikes. When plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound value is read off along a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the frame of the hammer.

Impact energy required for rebound hammer for different applications is stated in table 1 and 2:

Table 1. Impact energy required for rebound hammer

S.No.	Application	Approximate impact energy required for the rebound hammers (*N-m*)
1.	For testing normal weight concrete	2.25
2.	For light weight concrete or small and impact sensitive part of concrete	0.75
3.	For testing mass concrete i.e. in roads, airfield pavements and hydraulic structures	30

Source: [15]

Table 2. Rebound hammer types, impact energy and grade of concrete

Hammer Type	Grade type of concrete	Impact energy (N-m)
N	M-15 to M-45	2.2
L	Light weight concrete	0.75
M	Mass concrete	30
P	Below M-15	<2.2

Source: [15]

2.2.1 Methodology

Rebound hammer is basically a surface hardness with theoretical relationship between the strength of concrete and rebound number of the hammer. Rebound hammer test gives the hardness of the surface of concrete which can directly be converted to compressive strength with the help of the graduated scale attached in the body of the rebound hammer [9]. Before beginning a test, the Schmidt or rebound hammer should be tested against the test block, to get reliable results. For taking a measurement, the hammer should be held at right angles to the surface of the bridge structure. The test thus can be conducted horizontally on vertical surface and vertically upwards or downwards on horizontal surfaces. If the situation so demands, the hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.

The following things should be observed during test [15]:

- Surface should be smooth, clean and dry,
- The loosely adhering scale should be rubbed off with a grinding wheel or stone, before testing,
- Do not conduct test on rough surface,
- Point of impact should be at least 20 mm away from edge or shape discontinuity.

Across each point of observation, 15 readings of rebound numbers are taken and mean of these readings after deleting outliers as per Indian Standard (IS) is taken as the rebound number for the point of observation [15].

For testing, smooth, clean and dry surface is to be selected. If loosely adhering scale is present, this is rubbed of with a grinding wheel or stone. Rough surfaces resulting from incomplete compaction, loss of grout, spalled or tooled surfaces do not give reliable results which should be avoided. Measurement of rebound hammer is taken held at right angles to the surface of the concrete member [12]. Rebound hammer test is conducted around all the points of observation on all accessible faces of the structural element. Concrete surfaces are thoroughly cleaned before taking any measurements [15].

2.3 Principle of resistivity test

This test is used to assess the probability or likelihood of corrosion of the reinforcement bar and used to measure the quality of the cover concrete and also gives the idea of durability of concrete [15]. The corrosion of steel in concrete is an electrochemical process, which generates a flow of current and can dissolve metals. The lower the electrical resistance, the more readily the corrosion current flows through the concrete and greater is the probability of corrosion. So, higher resistivity indicates the good quality of concrete. The resistivity is numerically equal to the electrical resistance of a unit cube of a material and has units of resistance (in ohms) times length. The resistance (R) of a conductor of area A and length L is related to the resistivity ρ as follows [15]:

$$R = (\rho * L)/A \quad (1)$$

A current is applied to the two outer probes and the potential differences is measured between the two inner probes. The current is carried by ions in the pore liquid. The calculated resistivity depends on the spacing of the probes.

This is based on the classical four electrode system in which four equally spaced electrodes are electrically connected to the concrete surface. The outer electrodes are connected to a source of alternating current and the two inner electrodes are connected to voltmeter [15].

2.3.1 Methodology

One of the commercial equipment available for measurement of resistivity is resipod which is a four probe device used for measuring resistivity. The set of four probes are fitted with super conductive foam tips to ensure full contact on irregular surfaces [15]. Once the probes are kept in contact with the concrete surface, the LCD display will indicate the resistivity directly on the screen. The limits of possible corrosion are related with resistivity as stated below:

Table 3. Possible corrosion limitation

1.	With ρ = 12 K W cm	Corrosion is improbable
2.	With ρ = 8 to 12 K W cm	Corrosion is Possible
3.	With ρ = 8 K W cm	Corrosion is fairly certain

Source: [15]

Where, ρ (rho) is the resistivity

Measurement of resistivity test is carried out by cleaning the concrete surface. The concrete surface must not be coated with any electrically insulating coating. Dip the contacts in water several times before making a measurements. Press the resipod firmly down until the outer two rubber caps rest on the surface to be tested and note down the readings [12]. The following interpretation of resistivity measurements from the Wenner four-probe system has been cited when referring to depassivated steel for indication of corrosion rate as stated in table 4:

Table 4. Langford and Broomfield 1987 for corrosion rate indication

1.	>20 kΩ cm	Low corrosion rate
2.	10-20 kΩ cm	Low to moderate corrosion rate
3.	5-10 kΩ cm	High corrosion rate
4.	< 5 kΩ cm	Very high corrosion rate

Source: [15]

Empirical test for the application have arrived at the following threshold values for the measured resistivity which can be used to determine the likelihood of corrosion. This is given in table 5:

Table 5. Langford and Broomfield, 1987 for likelihood of corrosion

1.	When $\rho \geq 100$ kΩ cm	Corrosion is unlikely
2.	When $\rho = 50$ to 100 kΩ cm	Risk of corrosion is low
3.	When $\rho = 10$ to 50 kΩ cm	Risk of corrosion is moderate
4.	When $\rho \leq 10$ kΩ cm	Risk of corrosion is high

Source: [15]

Non-destructive test equipment’s are easy to use, reliable and time consuming. There are some limitations of NDT techniques such as results are qualitative, require qualified and competent personnel, requires the understanding the limitation in principle of testing and equipment and need to understand the tolerance and error margins [15].

Non-destructive test gives the idea of corrosion in reinforcement and durability of the concrete. There are many advantage of NDT techniques such as possible to have 100% inspection, more than one method can be used, inspection can be repeated, minimum or no sample preparation is required, in-service inspection is possible and instrument are mostly portable [14].

3 CRITICS

Gehlot, Sankhla and Gupta has stated that the investigation reported here is to present the studied of calibration graph for non- destructive testing equipment, the rebound hammer and to study the quality of the concrete of the structural elements (columns & beams) of single storied newly under constructed building of M.B.M engineering college Jodhpur. The use of this method produces results that lie close to the true values when compared with other methods [9]. However this test cannot be reliable to find out the existing quality condition of structure due to use of only single rebound hammer test. Further the conditional assessment and resistivity test is required to find out the existing quality of the concrete. There is a need of Conditional assessment, resistivity test along with rebound hammer test to find out the existing quality condition of the structure [12].

4 CONCLUSIONS

Engineering judgment is required to evaluate the data obtained from field measurement. Mis-interpretation of data may be possible to identify poor quality of concrete, which could lead to reinforcing bar problem. Non-destructive test (NDT) is used to find out or detect distress, deterioration and existing quality conditions of any structure like bridges, buildings, dam, etc. Visual inspection, condition assessment, non-destructive test such as rebound hammer and resistivity test are commonly used to find out the existing quality condition of the reinforced concrete structure. It is commonly used to monitor the reinforced concrete structure. Schmidth or rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between rebound index and the compressive strength of the concrete. It also provides an inexpensive, simple and quick method of obtaining an indication of concrete strength. In contrast, the resistivity test method is used to measure quality of concrete cover. It also provides the probability and chances of corrosion of reinforcement bar and gives the general idea of durability of concrete. Failure of concrete structures due to corrosion is a major problem causing significant loss of money and time. Hence, there is a need to understand root causes of failure of structure due to corrosion. The effective method to measure corrosion is a fundamental requirement for planning maintenance, repairing and removal for reinforced concrete structures. Information regarding corrosion can be provided through concrete resistivity test parameter. Condition assessment and NDT test is an important aspect for ensuring the existing quality of bridge along with its successful performance of a structure in given life span.

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REFERENCES

[1] M.J. Ryall, G.A.R. Parke, J.E. Harding Thomas Telford, “The Manual of Bridge Engineering” [Available Online], Thomas Telford Publishing, London, 2000.
[2] Thomas W. Ryan, P.E, “ Bridge Inspector's Reference Manual”, US Department of Transport, USA, 2002 and 2006.
[3] Hubert Gautier, “A bridge engineering book”, Encyclopedia Britannica, U.K, 1716.
[4] Mitra, A., “Fundamental of Quality Control and improvement (2nd edition)”, New Delhi: Prentice Hall of India, 2005.
[5] Feigenbaun A. V, “Total Quality Control”, McGraw Hill Inc., New York, 1991.
[6] FHWA, “Status of the Nation's Highways, Bridges, and Transit”, US Department of Transport, USA, 2010.
[7] Nayan Parmar, “Structural health monitoring by non-destructive test- a review”, “International journal of scientific development and research (IJSDR)”, Volume: 2, Issue: 4, pp- 284-286, 2017.
[8] Sanjeev Kumar Verma, “Monitoring corrosion of steel bars in reinforced concrete structures”, “The scientific world journal”, Volume.2014, no.1, pp: 1-9, 2014.
[9] Tarun Gehlot, “Study of concrete quality assessment of structural elements using rebound hammer test”, American Journal of Engineering Research (AJER), Volume-5, Issue-8, pp-192-198, 2016.
[10] Darshak Kumar V. Mehta, “Application of non-destructive test for structural health monitoring-state of the art review”, International Journal of Research in Engineering and Technology (IJRET), Volume: 04, Issue: 03, pp-105-108, 2015.
[11] K.V. Ramana Reddy, “Structural safety and rehabilitation of a college building: A case study”, International Journal of Structural and Civil Engineering Research (IJSCER), Volume: 3 no.3 pp: 55-62,2014.
[12] V.M Malhotra and N.J. Carino, (2006), “Handbook on Non-destructive testing of concrete”, 2nd edition, CRC Press, London, 2006.
[13] V.M Malhotra, “Testing Hardened Concrete non-destructive method”, IOWA State University Press and American Concrete Institute, USA, 1976.
[14] Kumavat H R, “Condition assessment of concrete with NDT – case study”, volume 3 special issue: 09, pp-63-67, 2014.
[15] IS 13311 Part 2, “Non-destructive testing of Concrete- Methods of Test”, India, 1992.
[16] IRC, “Standard specification and code of practices for road bridges”, section I, seventh revision, New Delhi, 1998.
[17] Victor, D.J., “Essentials of Bridge Engineering”, 6th edition, Oxford & IBH Publishing Company Pvt. Limited, New Delhi, 2013.
[18] DoR, “Nepal Bridge Standards-2067”, DoR, Government of Nepal, Ministry of Physical Planning and Works, Department of Roads, Kathmandu,2010.
[19] DoR, “Strategic Road Network of Nepal”, Department of Roads, Nepal, 2014.
[20] DoR, “Guidelines for Inspection and Maintenance of Bridges, Volume-I and II”, Department of Road, Kathmandu, 2003.
[21] Rashidi, M. and Gibson P., “Proposal of a methodology for bridge condition assessment”, Australian Transport Research Forum 2011 proceeding, Adelaide, Australia, 2011.